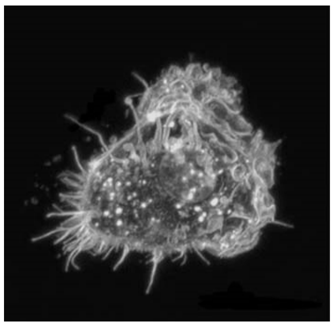

. . A Cellular Approach:

Understanding Architecture via Biochemical Pathways

A Thesis of Architecture

B. C. Bergeman

Ball State University

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Andrea Swartz, Studio Professor

Brian Hollars and Glenn Sweitzer, Architecture Advisors

Drs. James Pyle and Karlett Parra-Belky, Chemistry Advisors

Beauty does not reside in simplicity. Nor in complexity, per se. For a molecule or a song, for a ceramic vase or a play, beauty is created out of the labor of human hands and minds. **It is to be found, precarious, at some tense edge where symmetry and asymmetry, simplicity and complexity, order and chaos, contend**.

. . Roald Hoffmann

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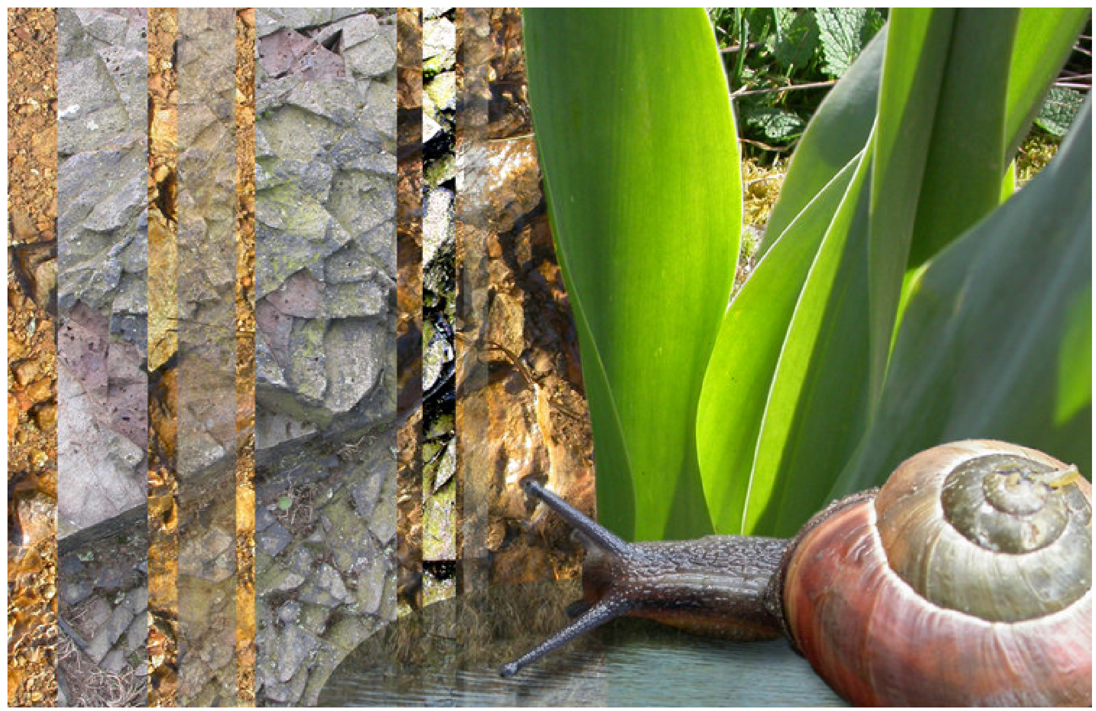
. . **Synopsis** [A Cellular Approach]

Can living cells, as fluid and complex organisms, be used as a dynamic model to achieve a greater level of efficiency and interaction in architecture? Biochemical pathways, for all intents and purposes, are universal across the spectrum of life and have perfected their achievements over millions of years. Cellular structures are flexible and adaptable, rendering even our most well-designed buildings primitive and clumsy by comparison. With a greater understanding of the metabolic, structural, and communication pathways inherent to cellular success, designers could adapt these concepts to improve the overall value of mankind's constructed environment.

At the core of this building/cell comparison is the consideration of long-term integrated purposes that address energy consumption, environmental impact, and community enhancement. This thesis -- the utilization of a human cell as an abstract model of healthier and more sustainable systems in architecture --tests a practical application of these concepts in a 30,000 sq. ft. National Education Resource Center located in a typical Midwestern community.



I don't like thinking of architecture as art because it objectifies it, and worse, makes it visual. I prefer the idea of architecture as cooking. This establishes very real conditions -- no one thinks rotten food is funny. When you eat, food disappears and changes your body.

. . Saitowitz

The significant impact the built environment has on the earth is of growing concern for scientists and citizens alike. American society appears laissez-faire in its current approach to design, as exemplified by sprawling seas of asphalt and inefficient planning. These irresponsible and short-sighted actions have contributed to the issues of resource depletion, high levels of energy consumption, and environmental pollution and degradation currently challenging the world. Humankind today can neither comprehend life without buildings, nor the built environment necessary for more than six billion people, but perhaps instead a world of better-quality buildings can be envisioned and achieved.

How should architects respond? New technologies and more efficient systems develop every day, but a society cannot rely solely on potential inventions to solve seemingly overwhelming problems.

A successful building requires both the elements of **community** and **energy/system** integration (Figure 1). Although 'sustainability' has become cliché in the design world, it does encompass the overall goal to design for the environment and people in a long-term manner that works to perpetuate itself. It is the synergy of both human and natural environment responsiveness that will facilitate design to

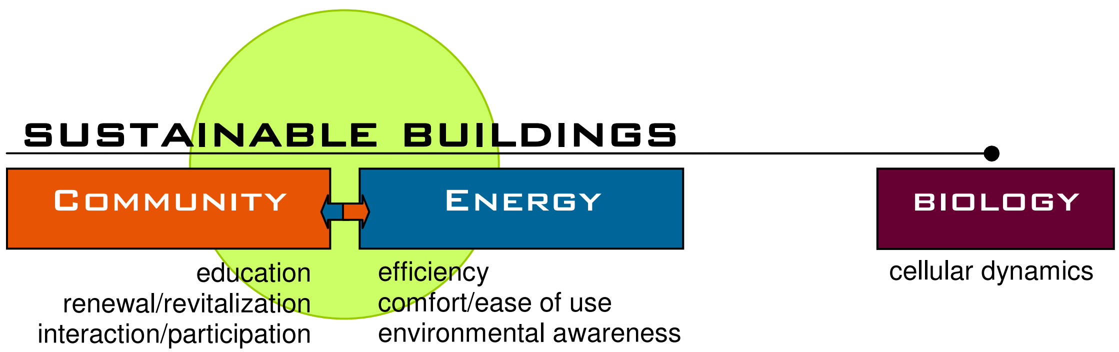


Figure 1.

Image 1 (above): The Petronas Towers glow in the night sky above Kuala Lumpur. **Image 2** (below): The seven-story building required to house the energy-intensive systems necessary to maintain the Towers.

exceed current standards of building function and utility.

The cell. As a dynamic model for designers, the ingenuity of life gives new meaning to sustainability in the built environment and sheds fresh light on the meaning of community and systems integration. Cellular function on a biological and molecular scale is unprecedented in its ability to adapt, recycle, create energy, and mediate between exterior and interior environments.

How can designers learn from the fundamental similarities between cells, and in what ways can this be applied to architecture? Here, a two-pronged approach of both physical and social interpretations intended as tangible applications, not abstractions, develops new modes of understanding and interacting with architecture.

Many connections can and have already been made between architecture and cells. Any subdivision of the built environment can be construed as a cell, from a neighborhood within a town to a building on a city block. The divisions within cells, or organelles, are like rooms where the daily functions of life are executed.

Image 3: The cellular nature of the city of Athens, Greece.

As pointed out by Dr. James Pyle of Ball State University, both architecture and cells deal with three significant issues: information, energy, and materials. When the means by which these operations are carried out are considered more closely however, existing commonalities are less obvious and the comparison begins to shed light on opportunities for development.

Physical Applications

Even within a larger tissue, the cell performs many tasks. If each cell were to "behave" like buildings in an American community, however, one cell would only treat waste, another would produce and modify all of the energy, another would contain the genetic material for reproduction, and still another would actually make the proteins. Impossible networks would be necessary to coordinate protein production and energy allotment. It's a problem faced by many cities across the country: people live in one location, work across town, their waste is processed elsewhere, while each of these energy-intensive processes requires different forms of energy from even more locations. Granted, some cells are better at processing energy than others, like a muscle tissue, and some organs are intended to deal with waste. For the most part, however, the daily functions of life are sustained by each individual cell. If the built environment contributed to the production of energy, addressed waste production, was not completely impervious to storm water and urban run-off, and promoted healthier working and living environments for people, then the impact on the surrounding environment would be less stressful and damaging, and resource consumption would not be as concentrated and subject to failure. For example, malfunction at one power plant or even on one power line can cause thousands of people to be without power; moreover, their livelihood is so dependant on that electricity that life can often come to a standstill. If each would produce a small amount of power individually, however, the network could more easily absorb such emergencies and potential failures.

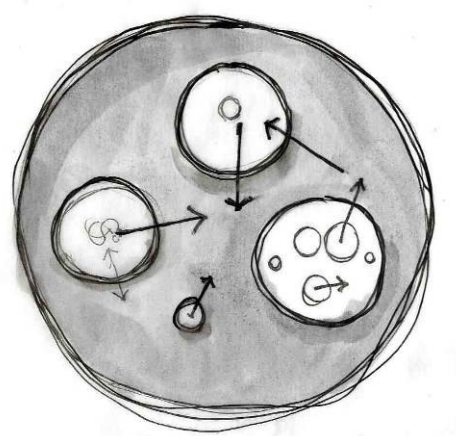


Figure 2: The movement within a cell can represent the flow of materials and energy within a building or information in society.

In what ways can a building redefine the meaning of resource? William McDonough and Michael Braungart have discussed this subject in their book *Cradle to Cradle*, but it becomes even more potent when considered within the context of cellular membranes. How can water movement, heat transfer, or air exchange become greater opportunities than they are today? Typically, movement through a wall occurs at a door or window, but what if the wall itself was able to spontaneously transfer materials, and even energize the building through this movement? In a cell, the movement of material across the membrane is used to capture energy – as if every time a user opened the door, a battery was charged. What if the building was able to create membrane potentials (or differences in ion concentrations), and recognize environmental influences and adjust is own permeability to account for these changes? Our buildings should not merely contain, but facilitate and enhance our lives. Man has achieved ‘shelter’ at an unprecedented scale, but the complexity of life today demands more from constructed space.

Social Applications

Socially, the building performs as many functions as it does physically to shelter people, and many of the issues previously mention allude to the inherent connection between buildings and the way in which people live.

Both explicit and implied signage and communication occur throughout the built form. In many ways buildings are symbols of social beliefs; the Ancient Greeks valued harmony and order derived from mathematics and science, while the Japanese sought the same unity through a manipulation of natural, organic forms. Thus, the architecture of today is the legacy of each generation to the next, be it the craftsmanship of a cathedral or the repetition of a chain restaurant.

Image 4: Light and shadow in the dome of St. Peter's Basilica, The Vatican.

Architecture also has the power to transform the spirit of man, and his fascination with the built environment has partly stemmed from the psychological impact of experiencing the three-dimensional world. The comfort of home, the holiness of the temple, and the ingenuity of the bridge are only examples of the social implications that constructed spaces hold for people worldwide. Buildings can educate and provide social commentary, define an era, and embody the aspirations of a social order. Just as poor design can numb the senses, thoughtful design can encourage communication and interaction or raise the spirit.

The urban building is an element of a larger context unified to perform a greater good; architecture does not have to dominate a community in order to enhance it. By integrating multiple uses into each element, a public building is more successful in its participation in the larger context and in bringing the people of a community together. The ability to interact with architecture, to touch its surfaces, to feel a sense of belonging or connection, and to derive a sense of personal investment and legacy are all fundamental to community pride and success.

In summary, the cellular model of architecture can represent the movement of materials, information, and energy within a building or the flow and absorption of ideas within a society. Both physically and socially, buildings can be informed by from the following cellular characteristics:

- Cells are organized into smaller groups, or "organelles" that perform a multitude of functions. Organelles are comprised of molecules, which are comprised of elements.
- The synergy of molecules, organelles, and cells creates a greater whole. Thus, nothing can be understood without an understanding of both the greater context and the smaller component parts.

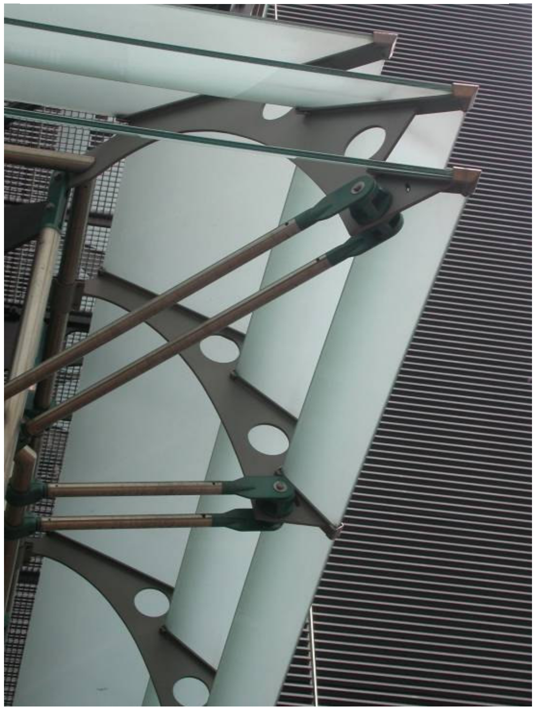
- Membranes are more than just barriers, and passage is more than a here/there occurrence. Transfer depends on the size and shape of molecule, and occurs through a series of transformative steps.
- While organelles and cell contain useful aspects of the cell, it is their membranes and their interactions with the interstitial space that is vital to most cellular function.
- The cell must perform at a scale appropriate to itself and its functions.

Limitations

There are, without a doubt, many limitations to the comparison of buildings and cells. This thesis can in no way be a comprehensive assessment of every way in which a biochemical allusion can or cannot be made, especially given the vast diversity of cells that exist. With the continual development of technological adaptations of the biological world, such as using photosynthetic pigments to produce electricity, there are many architectural applications that do not necessarily test the hypothesis of this thesis. Nor is the exploration of how building design can be informed by cell behavior meant to reproduce buildings as macro-scaled cells. Not only would that be impossible, this investigation is intended more as an abstract application of cellular concepts as they fit within an architect's understanding of design in an area that has seen little dialog between the two fields.

Regardless of these shortcomings, the comparison has produced tangible results as should be evident on the following pages. These structural units of life have been in existence for millions of years, and their success has made our own life possible. Eventually, the understanding of cellular viability could allow building success to be associated with the health of its users and the physical beauty and utility that the form contributes to its surroundings, thereby promoting a higher quality of architecture, and potentially life, for all.

Image 5: A sunshade in Zurich, Switzerland. The component parts, each with their own function and detail, enhances the quality of the design.



A teacher effects eternity.

. . Henry Brooks Adams

My heart is singing for joy this morning. A miracle has happened – the light of understanding has shone upon my little pupil's mind and behold, all things are changed.

. . Anne Sullivan

Introduction

The specific application of this thesis is a National Education Resource Center and Teacher Hall of Fame in downtown Muncie, Indiana. The building is both a documentary museum and a hub for new ideas and methods in teaching. Education is a defining element of American culture that often passes unnoticed and under-appreciated. Not only does the ability to retain and teach knowledge a mark of higher life forms, it has made the vibrant growth of the last one hundred years possible. Now with the vast array of facts, figures, and concepts available to mankind, it has become impossible for any one person to comprehend everything – making sources of information equally as valuable as sources of energy. In many respects, the teacher has become an 'organelle' in the greater body of knowledge available to mankind, and this program seeks to celebrate the accomplishments of those who have committed themselves to sharing and enhancing education.

Exhibits could range from topics on the development of kindergarten, civil rights and segregation in schools, and children's rights in the workplace, to changes in testing and discipline methods or the history of the #2 pencil. These exhibits would be based on the research being done by the visiting scholars of the resource center, while the Hall of Fame and display of student work would be designed to excite people about learning and interacting with other classrooms around the country. In all cases, the approach should be hands-on and interactive, engaging the visitor's interest and sparking new ideas.

Image 6: The earliest classrooms.

This building type is dynamic with multiple layers of use and public interaction. Its museum, office, retail, and café elements all involve different objectives at different parts of the day, therefore demanding flexibility. In addition, exhibits and nationwide inputs will be constantly changing as new research is done and classrooms around the country contribute to its displays. Thus, the building at 8 pm in June is not the same building at 8 am in December or even June the following year.

Location

There are several elements that make Muncie, Indiana, an excellent location for this facility. The Ball family, with the founding of Ball Teacher's College, now Ball State University, initiated a tradition of learning currently continued by the University and Minnetrista Cultural Center. Recognized nationwide as 'Middletown, USA' in the early 1980's, the community retains the spirit of Americana that citizens nationwide can identify with, and its size of approximately 118,000 people[1] makes it ideal for this type of building. There is sufficient opportunity for the community to support and invest in the program without its objectives and nationwide status overwhelming the town.

The following chart gives a brief summary of the programmed spaces necessary for the Resource Center.

	Space Requirements	Qty.	Size (sf)	Sub-Totals (sf)	Total (sf)
Entry	Lobby	1	2,000	2,000	
	Coatroom	1	400	400	
	Restroom	2	300	600	3,000
Museum	Small Auditorium	1	700	700	
	Projection Room	1	60	60	
	Exhibit Space	4	1,000	4,000	
	Hall of Fame	1	1,000	1,000	5,760
Administration & Research Offices	Museum Director	1	150	150	
	Exhibit Director	1	120	120	
	Marketing Director	1	120	120	
	Maintenance	1	120	120	
	Secretary/Waiting	1	120	120	
	Research Director	1	150	150	
	Visiting Scholars	2	120	240	
	Assistants	1	120	120	
	Secretary/Waiting	1	120	120	
	Conference Room/Public Classroom (10 people)	3	200	600	
	Conference Room/Public Classroom (30 people)	2	800	1,600	
	Lab	1	200	200	
	Kitchenette/Employee Lounge	1	300	300	
	Exhibit Creation/Workshop	1	750	750	
	Archive/Storage	1	1,500	1,500	4,950
Other	Retail	2	500	1,000	
	Café with full kitchen	1	1,500	1,500	
	Loading Dock	1	50	50	2,550
	Net Assignable Areas				16,260
			60% Efficiency Ratio		
	Estimated Gross Square Footage				**27,100**

[1] Indiana Business Bulletin. http://www.bsu.edu/web/bbr/IBB/STATE/MUNCIE/pop.htm. Accessed April 22, 2004.

General Space Requirements

Entry: Information desk and ticket counter will provide controlled access to Museum and Hall of Fame. There will be public access to conference rooms and administration offices [community]. The space will contain three-dimensional and

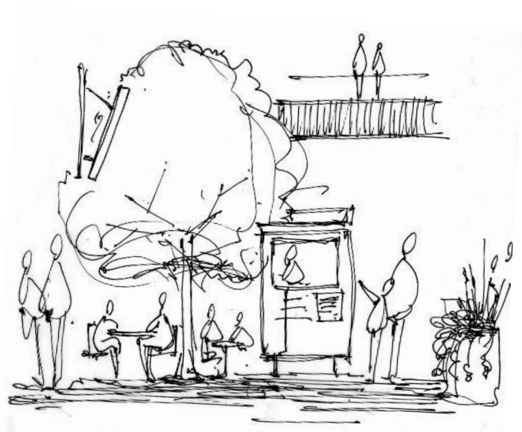


Image 7: **S**ketch of Atrium activities.

video displays of student work from around the country [communication]. Entry space will also contain a coat check and restrooms for both genders. This atrium should provide a direct connection with the street [diffusion] and should promote public interaction with interior spaces [interstitial space].

Public Museum: Four Exhibition rooms that patrons can take in a random sequence will be adjacent to entry space [absorption]. Daylighting should be filtered, and of a distinctly different quality than that of the main circulation spaces. Museum space must also have access to Exhibition Workshop and Archival rooms. The Hall of Fame (Figure 3) will house displays commemorating noted teachers, and will expand vertically over time to accommodate new inductees [cellular

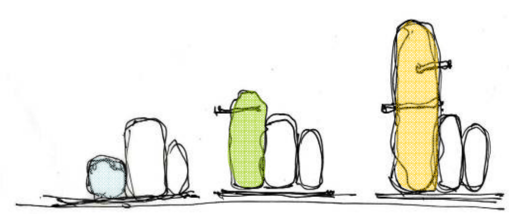


Figure 3: A conceptual sketch of the Hall of Fame's vertical growth over time.

growth]. Accessibility and vertical movement should specifically be addressed. A small auditorium for local presentations, museum films, and small group assembly (50-100 people) will also be included, while the proposed Symphony Hall, will be used for large gatherings and annual inductions to the Hall of Fame [integration].

Offices: Two Office pods are necessary, one for the director and marketing, exhibit, and maintenance staff of the museum, and a separate space for the research director, two visiting scholars, and assistants. These will share kitchenette and staff lounge [interaction], with access to Exhibition Workshop and Archival rooms. The Conference rooms will allow for education, gathering, and teleconferencing [interfacing], and will also be accessed by the general public.

Image 8: Existing mixed-use north of the site on Main Street.

Retail and Café: Spaces will be leased independently but should reflect the character of the Museum and Research Facility. There should be direct street access with high visibility, preferably on Main Street, relating to the existing retail to the north [context]. Sufficient storage should also be provided.

Space Relationships

The main entry will filter into an Atrium space with controlled access to Museum and Hall of Fame, and public access to Conference rooms, Offices, and Large Auditorium at the Symphony Hall. Offices should have private access to Museum; Museum will also have access to Workshop and Archive. There should be direct street access to Retail area and Café. Natural light and ventilation should be available to all spaces, though their quality may differ as the function of the space differs.

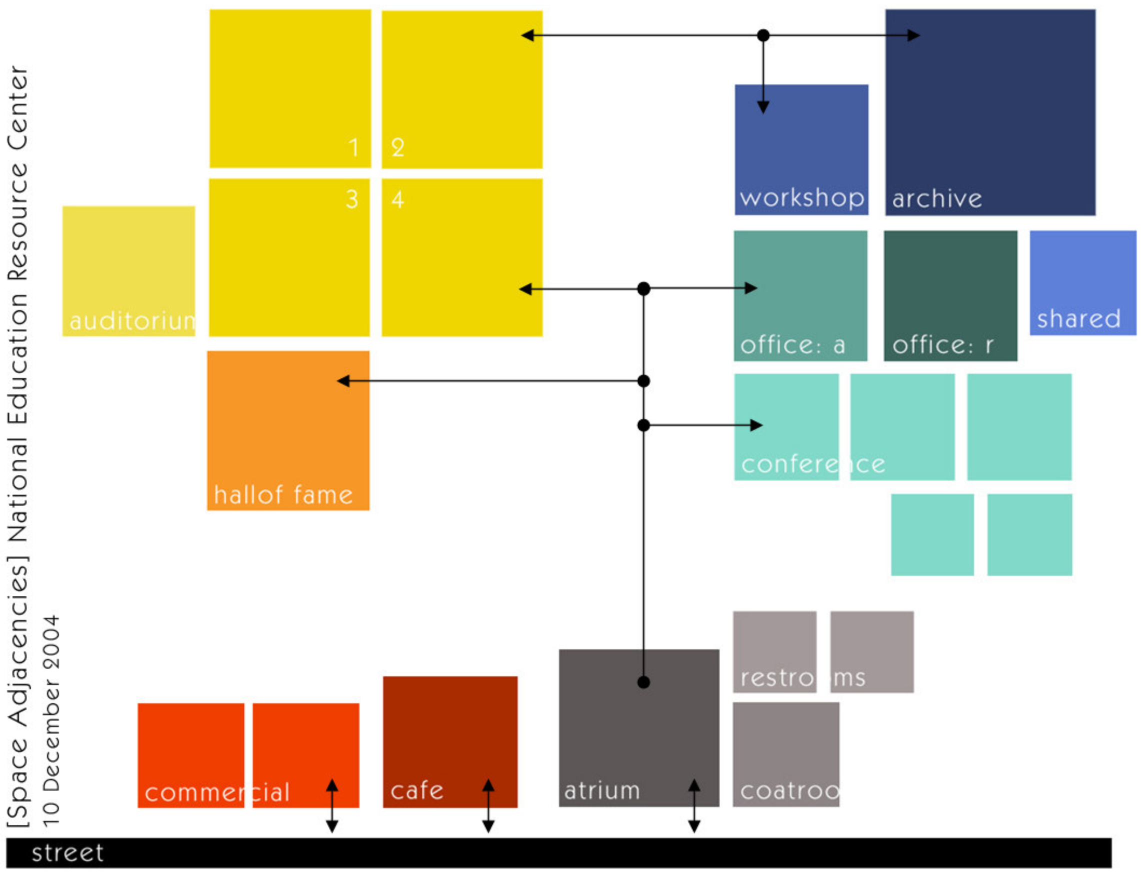


Figure 4: Space Adjacencies.

Clay is molded to make a vessel, but the utility of the vessel lies in the space where there is nothing. Thus, taking advantage of what is, we recognize the utility of what is not.

. . Lao Tzu

Site

In order to understand the application of the program to the selected site, the context was analyzed in several ways: the immediate physical aspects, the contextual relationships, and finally the building from the perspective of the larger 'organism' of the city.

Physical Attributes: Muncie, IN (Image 9), has an average elevation of 936 ft. above sea level, and is located at approximately 40ºN latitude and 85ºN longitude. The city is defined by the surrounding agrarian landscape and the

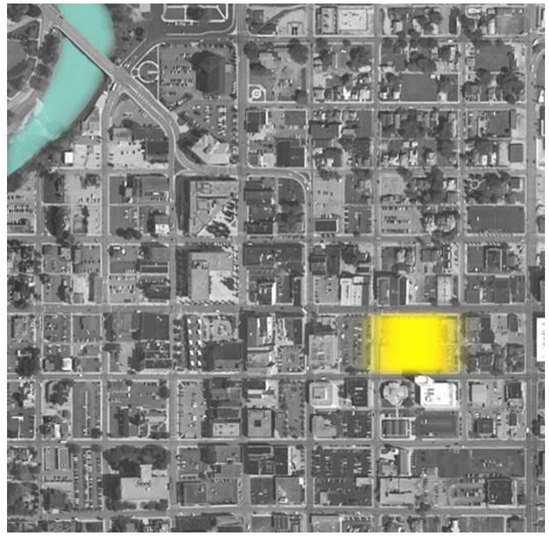


Image 9: Aerial photograph of Muncie, IN.

White River that flows southeast to the Ohio River. It experiences a full range of seasons; the average low temperature is 22ºF, while the average high is 75ºF. There is also a significant level of humidity present in late summer that can render outdoor temperatures uncomfortable. Annually, the city typically receives 39.6" precipitation, which is generally spread evenly across the year. Winds are most commonly from the southwest, though northwest and south east winds are also prevalent.

Contextual Relationships: The city of Muncie contains a variety of engaging places, those most relevant to this building being Ball State University, originally founded as a teacher's college; Minnetrista, a historical enclave of cultural artifacts celebrating the heritage of Muncie and the Midwestern region, and the Children's Museum, also located in the

Image 10 (above): Main Street façade, looking north. **Image 11** (below): Jackson Street façade, looking south.

downtown area.

The proposed block, bounded by Main Street to the north, (Image 10), Jackson Street to the south, (Image 11), and Elm and Jefferson to the east and west respectively, is currently used as a parking lot with one vacant building and one building being utilized by First Merchants Bank. Other buildings have previously existed there, however. On Main Street several historic storefront blocks, circa 1890's to early 1900's, contain a series of art-oriented businesses, including photography and framing, as well as the Civic Theater. This thesis assumes a 700 seat Symphony Hall has been proposed for the vacant site directly south of the Civic Theater and west of the proposed Museum. Thus, the retail spaces included within the program should support this developing 'Arts District' along Main Street.

At the southeast corner of Jackson and Jefferson Streets is the Carnegie Library, a neo-classical building constructed in 1903 that still houses central library functions. This proposal recommends the removal of the existing one-story brick building in the southwest corner of the block to allow the Library and the proposed Museum to share a public green space so users of both buildings could bring their activities outdoors. Any current use of the removed commercial building by First Merchants Bank could be located in the street-level vacant space within the mixed-use building west of the library.

City Organism: The analysis of Muncie also included a consideration of the city's grid, traditional among Midwestern towns, based on a 125' square module combined with 10' east/west and north/south alleys that formed

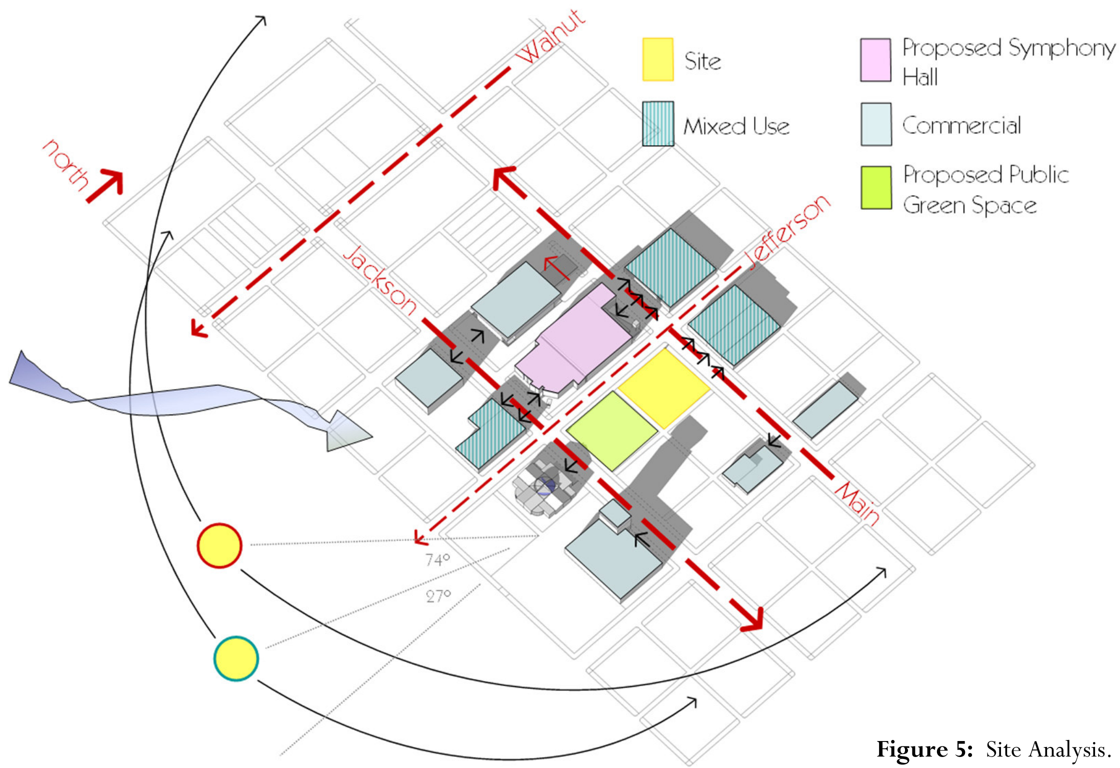


Figure 5: Site Analysis.

260’ square blocks. (Image 12). The site is actually located on a unique block within Muncie that is a combination of two additional 80’ plats, though its current use as a parking lot has negated most of the potential impact on the urban landscape. Each 125’ square was typically divided in half in one direction to form 62.5’ lots, which were often further subdivided into the 31’ or 21’ ‘shotgun’ lots that define traditional urban mixed-use structures. With the restoration of Walnut Street, two blocks west of the site, the existence of similar buildings directly north of the proposed site, and the inherent nature of cities to be established on this module, it seemed imperative that a ‘cellular’ building would do the same. Thus, an axis was formed on the north/south 62.5’ line that references the symmetry of the Carnegie Library to the south, and the retail portion of the building was positioned to enhance Main Street to the north. While the building does step over the 125’ boundary and the 10’ alley to the south, it still respects this aspect of the urban grid.

The site analysis, (Figure 5), also reflected on how other contextual buildings had addressed the street as a flow of people and material. The most successful buildings fronted directly on Main or Jackson Streets, establishing Jefferson and Elm as side streets. The program is not large enough to necessitate the entire block, so the building was placed in the northwest corner to enhance the boulevard aspects of Main Street, thereby allowing the public green space to the south to augment the public monumentality of the Carnegie Library and maximizing the southern exposure of the Resource Center.

Image 12: Typical plat layout for the city of Muncie.

. . Conceptual Applications

Form

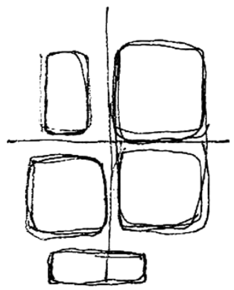


Figure 6.

Each of the programmed spaces were conceived of as self-contained 'organelles' within the larger building envelope (Figure 6); this allowed the axes and other interstitial spaces to develop into dynamic interaction zones and lightened the bulkiness of the building on the site. The massing studies were accomplished with a small study model comprised of these organelles, or functions, that could be rearranged to investigation different compositions (Image 13). This process tested the program and its defined adjacencies while allowing different interstitial spaces to be formed until the most appropriate were defined.

The atrium, envisioned as the center and life of the building, immediately shifted to the southwest quadrant of the building in order to take advantage of southern light and intermediate between the public green space and the more formal museum spaces within the building. Initially, the café was placed to the north along Main Street, but with further consideration, it was moved to the south to also take advantage of the southern light and the public green space. The retail space is located along Main Street directly north of the café, to promote high visibility and the sharing of the central loading dock with the café and museum. The 60 seat auditorium is located in the northwest corner, completing the four quadrants of the First Floor. Entry into the building occurs between the atrium and café on the south side, or at the northwest corner beneath the Hall of Fame (Figure 7).

Image 13: Massing model comprised of five pieces: Atrium, Retail, Hall of Fame, Museum, Classrooms.

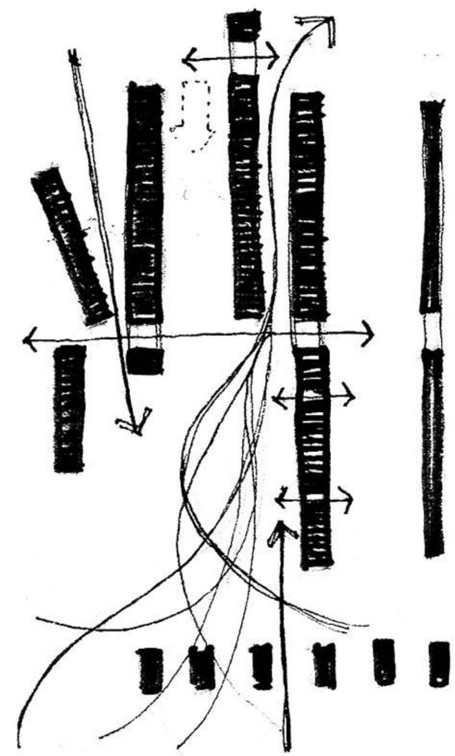


Figure 7: Structural walls create membrane layers that channel the movement of people, light, and air.

On the Second Floor, the Hall of Fame initiates its upward spiral as it winds around the space directly above the auditorium, in the northwest sector. To the east, above the retail space, are the archival and exhibition creation spaces with easy access to the freight elevator and loading dock below. To the south, in the southeast portion, is the first level of museum spaces, and pulled away from the building to the south are the administration offices accentuated with opportunities for cross ventilation and excellent views of the public green space. The offices also shade the front steps in summer, making them more enjoyable for gathering and café dining.

These three quadrants and the offices form a reversed " C " shape around the atrium that is essentially duplicated on the third floor, though the entire east side is given to museum display space. Finally, the fourth floor is only occupied by the upper level of the Hall of Fame and the classroom/conference spaces that open up onto a south-facing patio. Archival and Storage spaces are predominantly located in the lowest level of the facility, below grade, to reduce exposure to natural light and maintain a close relationship with the service elevator. Mechanical spaces are also located on this level.

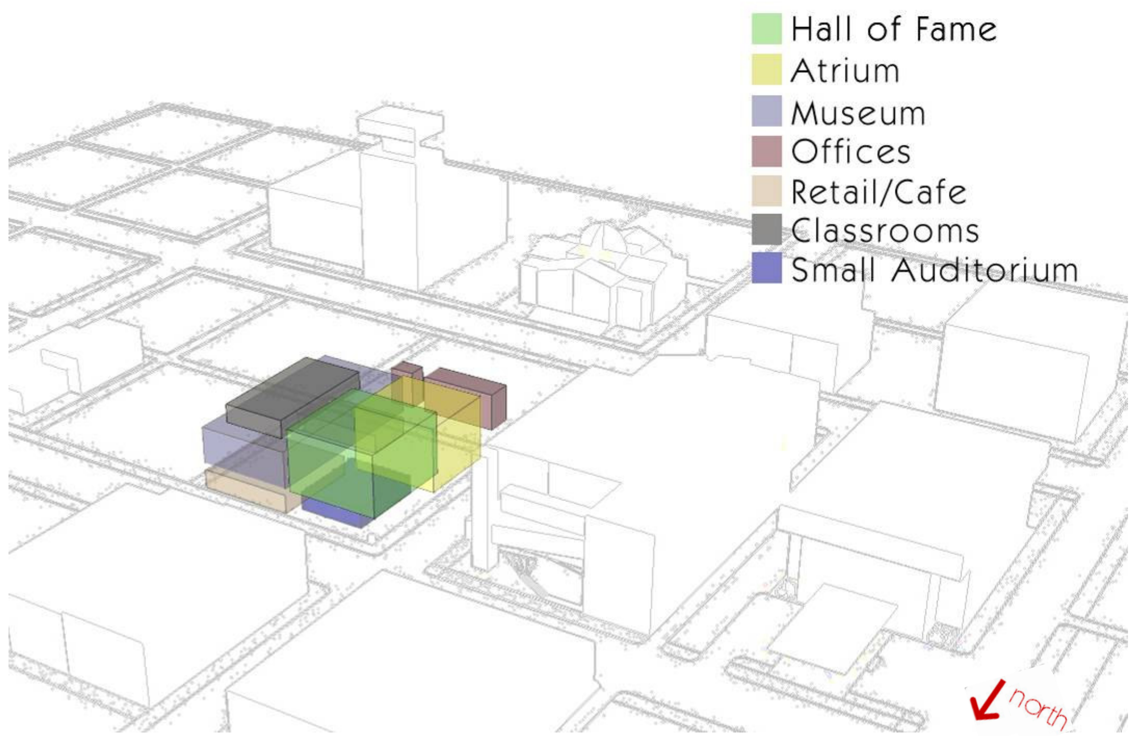


Figure 8: Schematic massing within the city context.

Sequences

The building is best understood as a series of sequential experiences as if each process within the building is a kind of membrane into the next.

From the south, one would most likely approach through the public green space (Image 14). The building is shown from the front steps of the Carnegie Library, along Jackson Street.

The offices, pulled away from the building and supported on steel and gabion basket columns, become a modern 'porch' that references that of the Carnegie Library [connection]. As one moves closer, one may notice that water, collected on the roof, runs through the rock baskets and along the main axis to the central pond [resource]. The steps beneath the offices, comprised of limestone blocks and grass, are perfect for gathering and extending the café's eating space [interaction].

After crossing the porous pavers of the drop-off zone, visitors enter the building on the visual axis that extends north to Main Street. Ahead to the left is the information and ticket counter, and to the right, a four-story limestone wall is cut by the restrooms and café while the second floor seems to hover above. Once inside, the space opens into a three-story atrium defined by a sweeping stair, plantings, and a pond that purifies the building's wastewater [living system]. TV displays play images taken in classrooms across the country, as different levels of activity converge [interstitial space].

Image 14: Resource Center from Jackson Street.

Image 15: Front steps.

Image 16: Atrium.

Image 17: Jefferson Street looking south.

From the north, the corner of Jefferson and Main Street is framed by The National Education Resource Center and the Symphony Hall (Image 17). At night, the illuminated Hall glows warmly above the city [node]. At the street, the building's massive walls break down to allow pedestrians to move around and between them or sit along the edges (Image 18). The formal entry (Image 19) occurs between converging limestone walls, the ceiling height rising as one approaches the narrowest point [threshold]. Unseen openings overhead filter light, increasing the spirituality of the space and the engraved words that document the spirit of education in America, preparing the visitors for the journey inside [transition]. The ceiling level lowers to compress the space, only to open up into the light-filled atrium (Image 20). The student display space, defined by the central stair, is directly ahead, while the offices on the second and third stories can be seen beyond. During the summer, the glass doors of the south and southwest walls can be rotated open, to allow cool breezes inside and exhibitions to spill into the street [diffusion].

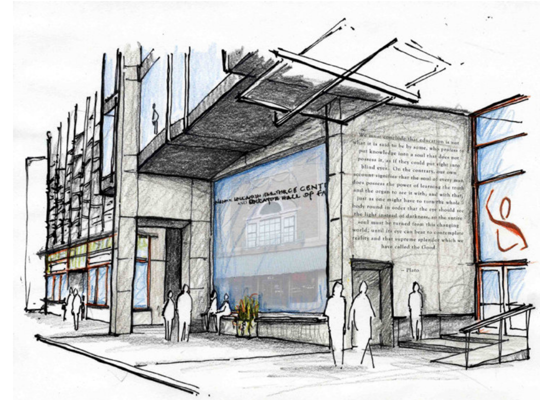


Image 18: Main Street façade.

Image 19: Passage between exterior and interior environments.

Image 20: Atrium from the north entrance.

To reach the Museum spaces from the Atrium, one can either take the central stair or the elevator (Image 21). Initial visual links give cues to museum content, but people can only enter at a certain locations [facilitated transport]. Next, (Image 22), people will see the Carnegie Library as it terminates the visual axis, a symbol of knowledge in America, as well as the offices of the researchers and administrators [connection]. To physically enter the Museum, one crosses the gap between the circulation and the documentation organelle, and passes through the massive limestone wall, into a room with a different quality of light and air temperature due the nature of the displays (Image 23). These exhibits are set up on a grid, and can be rearranged as need. Floor/ceiling panels can also be removed to open the space up to the floors above and below [adaptation]. Since the expectation is for the exhibits to change with the expertise of the visiting scholars, this museum is one that can be visited annually with different experiences each time.

Image 21: Atrium from the central staircase, looking southeast.

Image 22: Interstitial space between Atrium and Museum.

Image 23: Museum displays.

The Hall of Fame also begins on the second floor (Image 24), and is equally interactive. Here, touch screens give visitors the opportunity to watch a teacher give their favorite lesson plan or discuss an important issue in education during their lifetime [connection]. Periodically, the ramp levels out to cut through a limestone wall into the interior space above the auditorium where a large, sculptural piece is highlighted with accent lighting. Visitors can take the Hall at their own pace, and each level returns to balconies overlooking the atrium [interstitial space]. On the right of the top image, smaller sub-spaces for gathering, discussion, and short films; becoming an opportunity for interaction among patrons [interaction].

Image 24: Second Floor **e**ntrance to Hall of Fame.

Image 25: Hall of Fame displays.

Image 26: View from the second level of the Hall of Fame to the Atrium.

The interior walls of the public classrooms and conference spaces on the Fourth Floor can be reconfigured to open up to one another and onto a south facing patio (Image 27). This provides views of Jackson Street, the Carnegie Library, and the city of Muncie beyond [connection]. Teleconferencing allows an even larger world view, as groups can interact with teachers and classrooms around the world in an effort to share information and knowledge [communication]. The roof of the building is designed to collect rain water, and with the implementation of photovoltaic panels, to generate electricity for the center [resource].

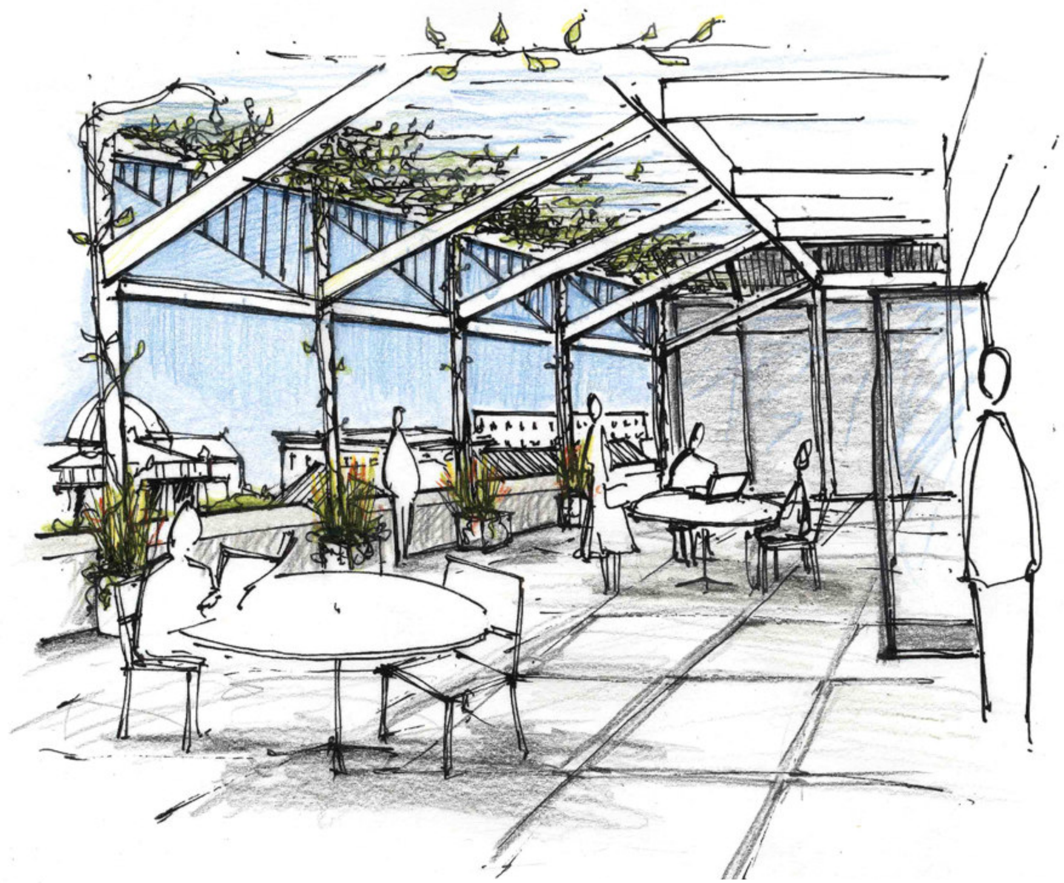


Image 27: South facing patio, planted with vines, becomes a relaxing gathering space.

Metabolism and Membranes

The building also achieves a number of ‘adaptations’ to better integrate with its environment.

The organelle nature of the program expressed in plan is also present in a sectional analysis (Figure 9). This is made possible by using a space frame, supported on the masonry walls, as the floor system in the museum spaces. The component nature of space frames allows for several flexible opportunities (Figure 10). The frame would allow easy access to the contained systems, prefabrication and assembly, and a variety of ‘fillers’ that change depending on the space frame’s location and purpose. Thus, an exterior wall composed of these pieces could contain rocks and soil with climbing plants, while an interior floor would contain air ducts and plumbing. Breaking the structural system down into reproducible components has a direct connection with the phospholipids components in the plasma membrane of a cell.

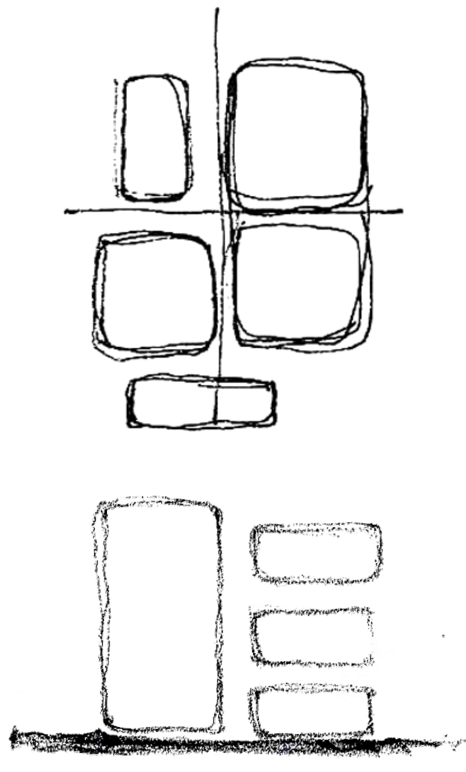


Figure 9: Plan and section analysis of organelle structure.

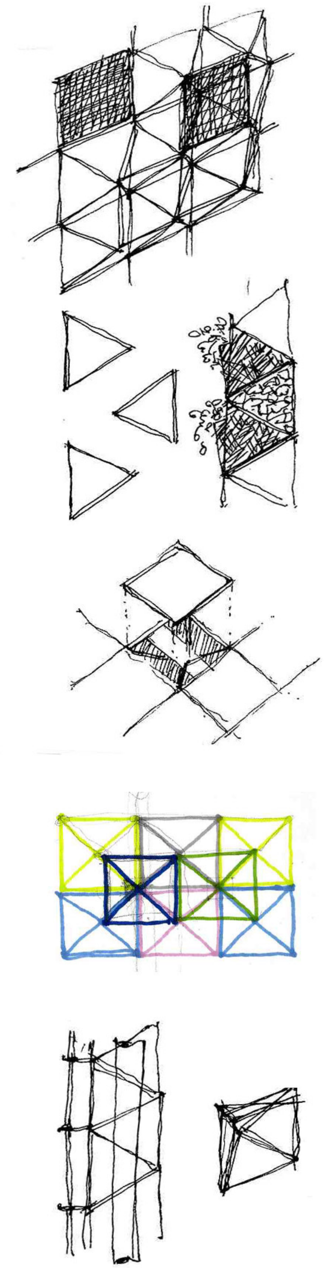


Figure 10.

Figure 11 illustrates several of the shifts that can occur to adapt the building to its environment. In the café, the glazing of the south wall is flush with the south façade to maximize solar gain and to create a warm, sun-lit eating experience. During the summer, the wall is pulled back to create an overhang, allowing airflow and shading the occupants from the sun. During favorable weather, the wall of the atrium can also open to allow air to enter the space to facilitate stack and cross ventilation, while also allowing displays to more visible to the street. When presentations are being made in the auditorium, the space performs like a typical room for large gatherings. When it is not in use however, the ceiling grid opens up into the Hall of Fame above, while the one way mirror to the north allows visitors to watch the street beyond.

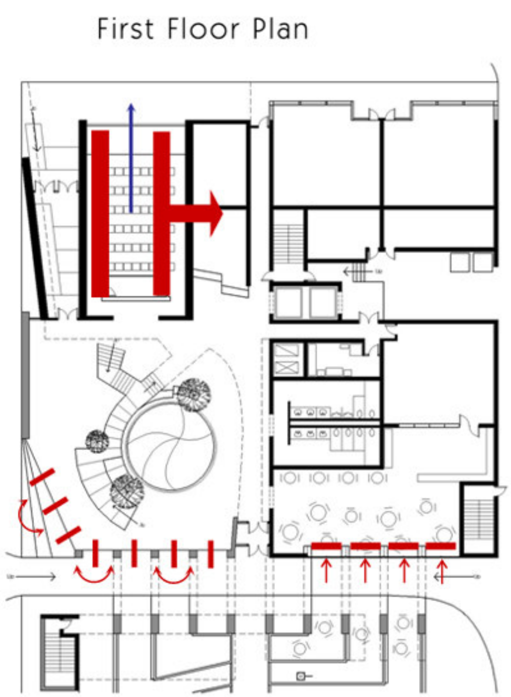


Figure 11: Variations of the First Floor.

The sequences previously mentioned (Pages 25 – 30) are also a type of membrane that psychologically transforms people as they pass through them. For example, in the sequence that takes people from the Atrium to the Museum, visual cues initiate the process Figure 12). The image of the Carnegie Library forms a social connection with a symbol of education in America. The crossing of the gap further enhances the monumentality of the difference between Atrium and Museum, and the change in environment (light, humidity, acoustics) completes the perception of passage.

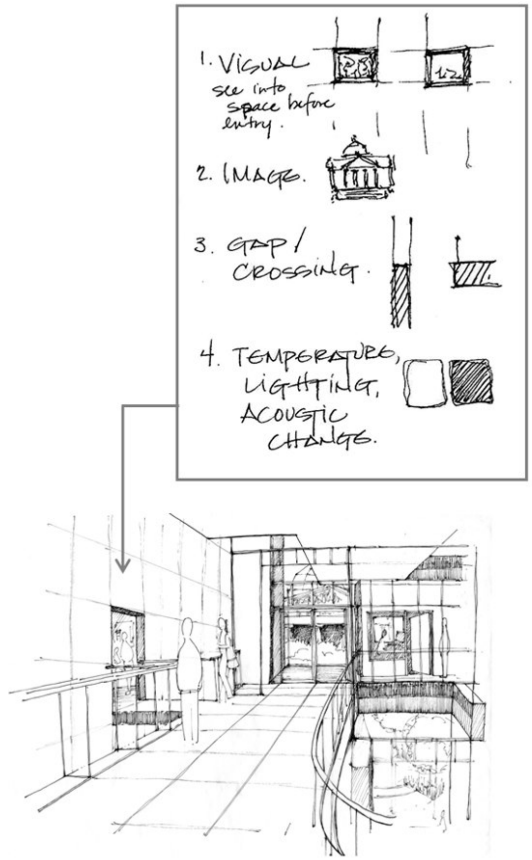


Figure 12: Passage sequence.

To better understand the function of the building within its environment, the heat gains (both solar radiation and internally generated) were graphed for each quadrant of the building (Figure 13). When compared to the external temperature for each month, the necessity for additional heating and cooling is more readily apparent. For these balance point temperature graphs, when the building temperature line is above that of the outdoor temperature, then heating is required, and when the opposite is true, cooling is necessary to achieve comfort within the building. For example, in January all spaces will require some form of heating, while in March the Atrium will have excess heat in late afternoon that could be distributed amongst the other rooms. In June and September, all of the spaces require cooling by late afternoon. The exterior temperature drop around 4 am indicates that night cooling may be a viable strategy, however.

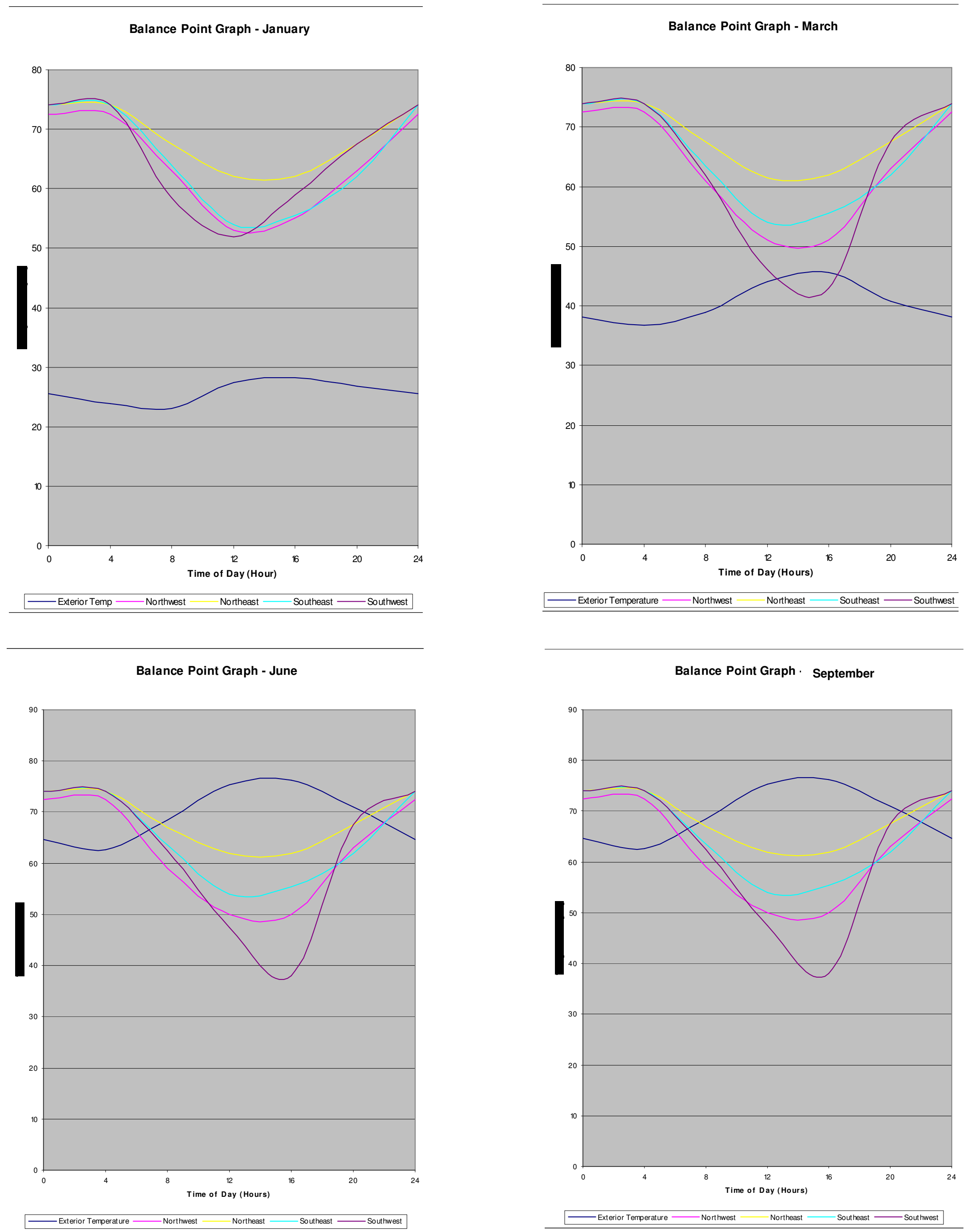


Figure 13: Balance point temperatures based on quadrant and month of the year.

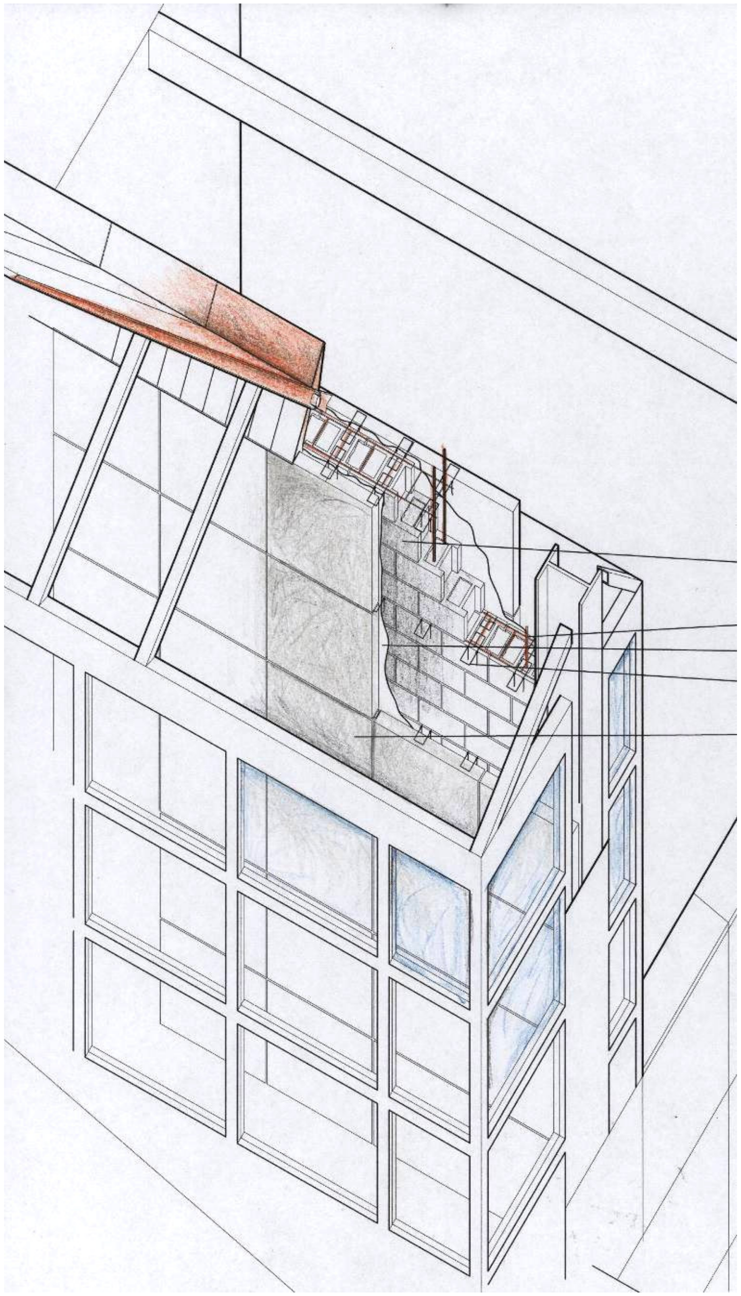


Figure 14: Axonometric drawing and section of stack.

Stack ventilation is a means of achieving more comfortable temperatures within a building. By causing heated air to rise due to a difference in exterior and interior temperatures, cooler, higher pressure air is pulled into the vacated space. This exhausts stale, warm air while users perceive a comfortable movement of air. By capturing solar radiation in a glazed space around the central axis wall, air is heated (Figure 14). During the summer, this warmer air will rise and be exhausted, drawing cooler air into the building through the atrium. In the winter, the pre-heated air would instead be drawn into a traditional forced air system (Figure 15). The limestone and masonry wall would act as a solar mass, maintaining greater heat levels and therefore higher temperatures, maximizing ventilation opportunities late in the day when radiation is not its highest but built-up heat in the building needs to be exhausted.

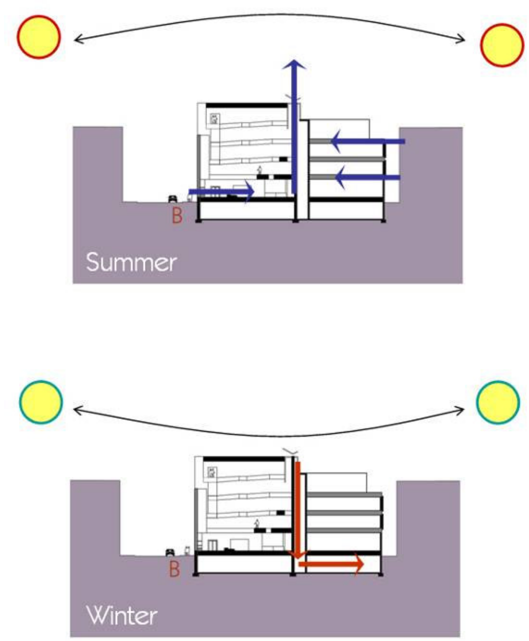


Figure 15.

The roof of the National Education Resource center is designed to collect water and direct it down the south façade. The water crosses over the drop off zone to the gabion baskets that encase the columns that support the offices. Trickeling through the rocks and leaving behind impurities, the water moves along the steps to the central pond (Figure 16).

Image 28: Gabion baskets used for water drainage in a train station in Zurich, Switzerland. (Photo courtesy of Catherine Reek).

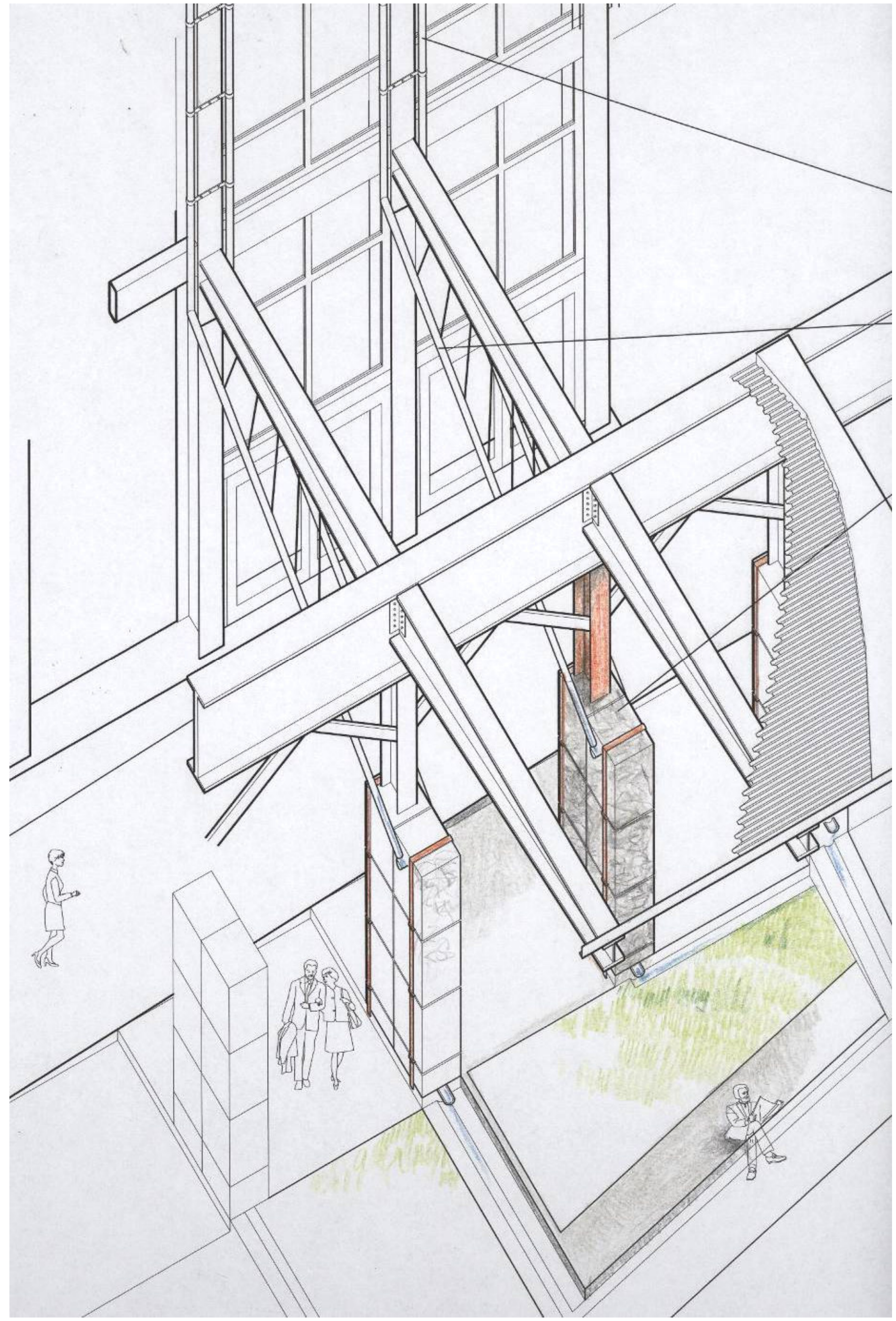
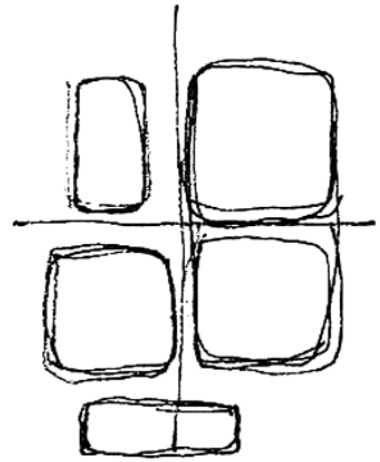


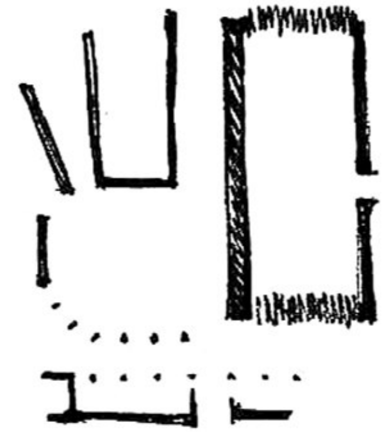
Figure 16: Axonometric drawing and section of south façade.

Thus, the building performs a variety of functions via systems that are integrated into its structure and form. When each is expressed individually, only a limited understanding of the structure is possible; it is only by layering all of the elements of axis, sequence, air flow, light, water purification, etc., is the building complete.

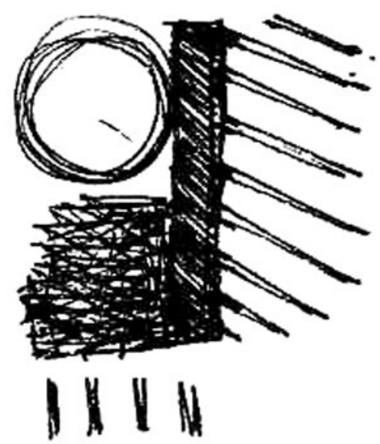
Figure 17: Membrane Diagrams for different systems.



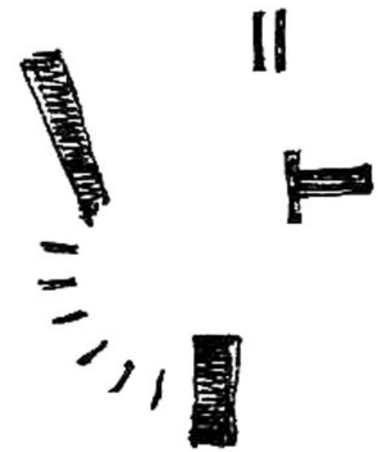
Program Diagram [Organelles]



Structural Diagram



Air Flow Diagram [Stack and Cross Ventilation]



Entry Diagram [People and Materials]

. . Conceptual Applications

Building

The final building form encompasses both the social and physical aspects of cellular processes. Its program, position on the site, interior spaces, facades, and contextual references have all been influenced by the cellular model, but are still recognizable as a built form.

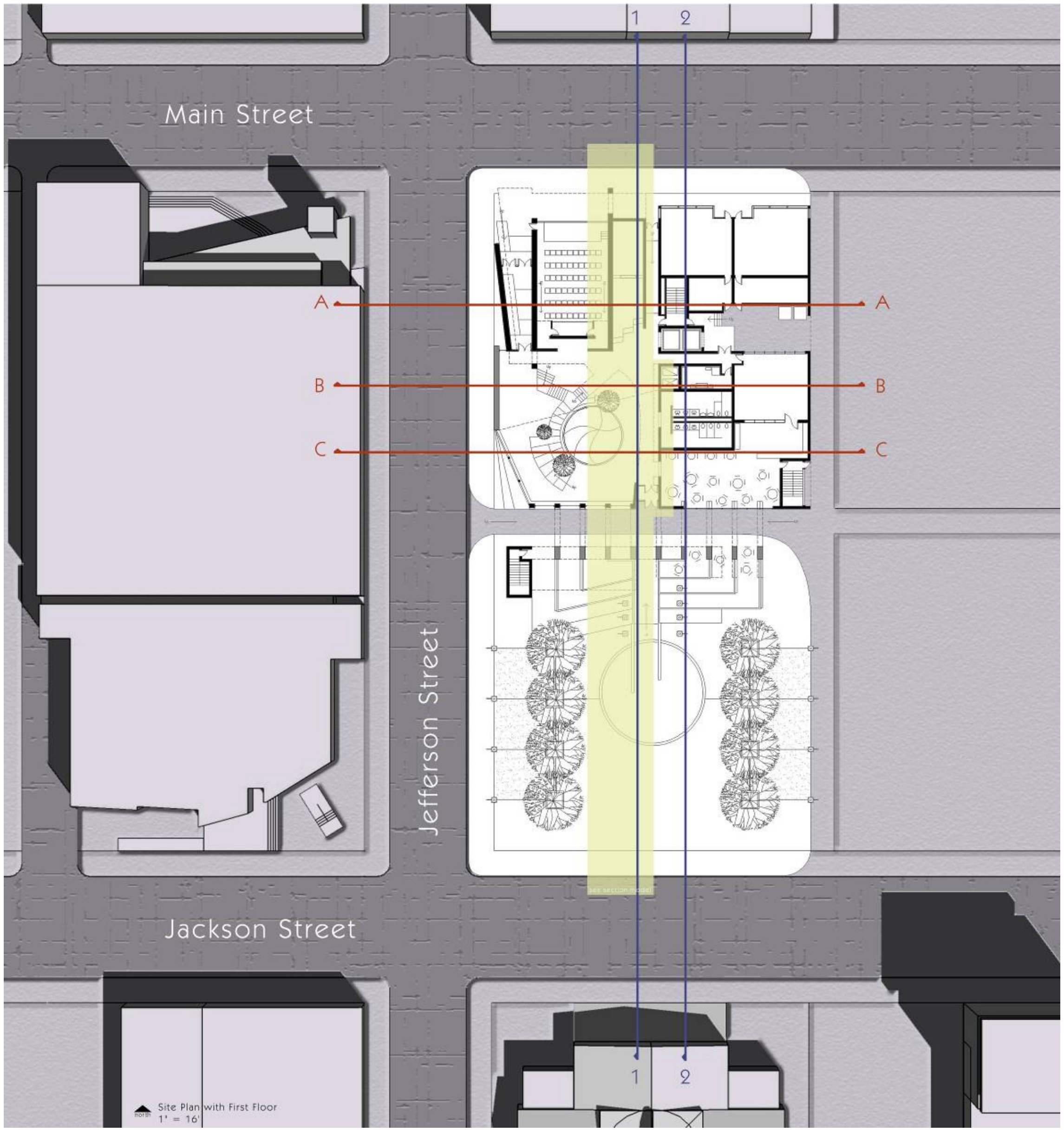


Image 29: Site Plan with First Floor Plan and section lines (Page 39). Central band indicates location of section model (Page 57).

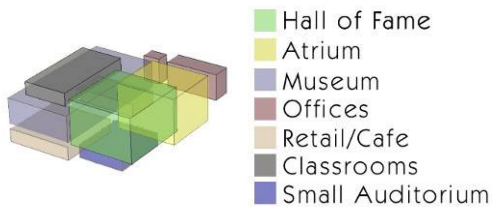


Image 30: Floor Plans.

Image 31: Building sections and elevations.

I must confess to a feeling of profound humility in the presence of a universe which transcends us at almost every point. I feel like a child who while playing by the seashore has found a few bright colored shells and a few pebbles while the whole vast ocean of truth stretches out almost untouched and unruffled before my eager fingers.

. . Sir Isaac Newton

Conclusions and Potentials

Both architecture and cells involve an environmental response to information, energy, and materials. These similarities include a structural differentiation of spatial functions and utility, complexity of transition and passage sequences that heighten the utility and psychological power of architecture, and interstitial space that engages activities and enhances the utility and dynamic nature of the design for the people who use it.

Realistically, the building type explored could have been anything, and the true success of the building would lie in a community of similarly engaging structures. When every building plays a part in enhancing the greater built environment, then the accomplishments of American society will not only benefit the Earth, but the success of mankind.

There are also missed opportunities within the building presented here, and elements that could have seen further development. The goal of the cellular model is to generate the greatest efficiency possible. For example, the movement of air through the stack ventilation system could also drive turbines, or water run-off against the south façade could be passively heated in the winter to radiantly heat the building. A healthy wall would never seal occupants off from air exchange with the exterior environment, but would still maintain thermal comfort and air purity.

The majority of materials utilized in this thesis – concrete, limestone, steel, glass – are common throughout the built environment. The development of new materials could enhance the potential gain of understanding cell/building relationships, although the coordinating the form, programming, and total building system is far more relevant. Materials that expand and contract to address humidity/temperature levels, materials that can be completely broken down and reused to reconfigure spaces, or that will allow the passage of materials, light, or air to capture energy for the building or remove wastes will revolutionize our understanding of 'architecture' and its role to facilitate society.

When the cellular model is broken down to its most fundamental level, one realizes the dynamic aspects of life are achieved by a synergy of component parts that form interactions without ever physically touching. A chemical bond is not a bolted connection,

Image 32: A soap bubble.

but the attraction of force fields; the fluidity of the plasma membrane is derived from the fact none of the phosolipids are bonded together. Differences in polarity and concentration hold them together, as if defying gravity, in an intricate dance that both allows and prevents permeability and supports large proteins. The daintiness of this balance is unparalleled in the human world, though a soap bubble is a rudimentary example (Image 32). Only when architects can realize this level of delicacy in their design will the built environment achieve the level of sustainability that has preserved life on Earth for millions of years.

Image 33.

The goal of the project was to test the established perception of architecture with a new model that had not previously been associated with the field. Chemists have a different process of thinking than most architects, and a unique way of approaching problems that involves an evaluation of cause and effect with an element of reverse engineering. In many cases, a chemist is presented with a result, like a molecule or data from an experiment, and they must work backwards to understand the process by which that result was achieved. Too often, architects perceive buildings as absolute, visual objects, like a sculpture or a rock on the landscape, and the greatest influence of the cellular model may be to understand buildings as cause/effect relationships with their context, environment, and the people who use them. Thus, the derived forms of the design process are dictated by the nature of life and not abstract impositions by a designer.

Without a doubt, the methods presented within this thesis are a more intensive and complex way of designing. When the building is conceived of as a mechanism, and not a stationary object, the number of considerations necessary for its success increases significantly. Many of these goals are achievable today, however, if people are willing to interact with their environment, from opening a window to enjoying another's company. When people expect their building to be tools for living, then design will be forced to the next level of complexity and integration necessary for future generations. Architects can no longer exclusively view the built environment as a money-making endeavor, but as an opportunity to make the world a safer, healthier, more enjoyable place to be.

When I am working on a problem I never think about beauty. I only think about how to solve the problem. But when I have finished, if the solution is not beautiful, I know it is wrong.

. . Buckminster Fuller

A Biochemical Background

A bond is a relationship of electrons between two atoms. Bonds may be weak interactions between positive and negative particles (ions) or a physical sharing of electrons, but either way they represent captured potential energy. Water (H_20) is a polar molecule, meaning that the electrons comprising the bonds between each hydrogen and oxygen are not shared evenly. For this reason (and others), the hydrogen ends are slightly more positive than the negative oxygen end (Image 35). This interaction between multiple polar water molecules is what allows ice to float, surface tension, the heat capacity of water, and water's ability to dissolve other polar or ionic molecules.

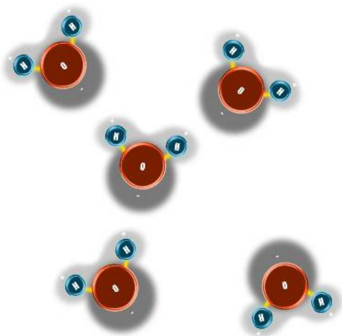
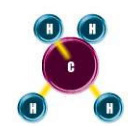


Image 35: Water molecules.

Organic molecules are defined as chains of carbon and hydrogen atoms; the inclusion of nitrogen, oxygen, phosphorus, sulfur, and a limited variety of other elements defines how they react to other molecules. These 'hydrocarbons' follow strict bonding and basic polarity laws, the most simple being methane, (one carbon and four hydrogen - CH_4), to proteins that may contain thousands of atoms. Carbon always bonds four times, and the angles of its bonds form a tetrahedral shape: instead of being 90 degrees apart, they are actually 109. Hydrogen and carbon share electrons evenly when they bond, meaning that their bond is non-polar and therefore, not charged. The difference in polarity causes polar and non-polar atoms to not interact with each other when they are in contact, as is the case with oil and water.



Conformational changes, like the angle of certain bonds, location of a functional group, or molecular orientation, can determine the utility of the molecule and how the body works with it. Structure is integral to reactions the cell must perform in order to survive; a discrepancy can dictate the speed and likelihood of a reaction. Molecules can be comprised of exactly the same elements but in different shapes and orders, rendering it useless or even toxic to the cell. For example, your right and left hands have the same number of fingers and thumb, but the orientation to the palm is different, making their operation different.

Biological molecules are classified in four major categories: carbohydrates, lipids, nucleic acids, and proteins. Carbohydrates, the simplest being mono-saccharides like glucose, are rings of carbons bonded to oxygen and hydrogen that form huge starch chains. The category of lipids incorporates fatty acids, triglycerides, and membrane lipids that involve hydrocarbon chains. Fatty acids are a denser energy source than carbohydrates, but both are used by life forms to store energy. Nucleic acids, like DNA and RNA, are comprised of nucleotides whose sequence define the genetic material of the cell. These sequences code for chains of amino acids, which fold to form proteins. Proteins, in the form of enzymes, structural elements, and transportation mechanisms, are the work horse of the cell.

Material Exchange

The plasma membrane of animal cells is comprised of a double layer of phospholipids, or two non-polar hydrocarbon chains connected with a polar 'head' that surround the cell in all directions. This forms an interior non-polar space isolated from the aqueous interior and exterior of the cell. Soap works in a similar way, only each polar head has one non-polar tail. They form spheres around oil and dirt particles, polar heads towards the water, non polar tails interacting with the oil. When rinsed, the soap washes away and removes the oil with it.

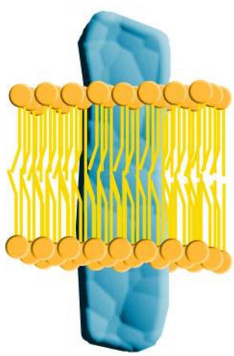


Image 36: Membrane.

The membrane of a cell is interspersed with proteins and is responsible for the containment and separation of the cell, material exchange, information and communication with other cells, attachment and structure, movement, and basic metabolism. Such a diverse role in the success of the cell has made the plasma membrane especially efficient, just as it is fluid and adaptable. Each phospholipid of the membrane may change places with its neighbor thousands of times per second, and proteins are constantly moving between the lipids.

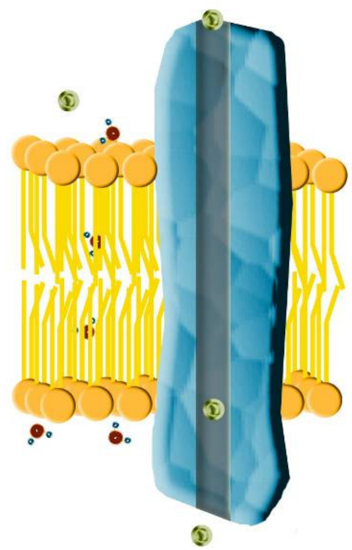


Image 37: Membrane transport.

Amazingly, the cell has developed a variety of means for moving molecules across its membrane: diffusion, passive transport, active transport, and endocytosis. First, small molecules like oxygen and water are able to diffuse between the phospholipids in and out of the cell. Ions, like sodium and potassium, are transported through facilitated diffusion, or protein channels that allow their movement. They cannot move through the membrane itself because of the difference between their charged nature and the uncharged inner space of the membrane. This movement of ions creates gradients of concentration. Water spontaneously diffuses to the area of higher ion concentration, so if more sodium ions are outside of the cell, more water will move out of the cell than back inside. Therefore, cells control the ions as a means of indirectly controlling water. These charged particles also create a membrane potential, or electric difference between interior and exterior that can be as much as 20 - 200mV. For larger molecules, proteins located within the membrane allow them to be actively transported. Here, the molecule bonds to a protein, a series of structural transformations occur because of that change in shape, and the molecule is released across the membrane. This requires energy, however, which the cell can capture in a number of ways. Finally, the membrane can actually envelop or dispel large molecules or even other cells by forming a membrane around it, merging that membrane with the plasma membrane, and then releasing its contents on the other side of the membrane. This is called endocytosis; most people are familiar with amoebas which use this technique to engulf their food.

Energy can be gained or consumed by the methods mentioned above. The sodium/potassium pump is a commonly studied means of doing this. Sodium on the inside of the cell is pumped, against its concentration gradient, into the intercellular space outside of the cell, using potassium ions flowing down their concentration gradient into the cell as an energy efficient means of exchange. Then, a different protein uses the extra-cellular sodium ions moving down the gradient to move glucose, a large molecule, into the cell. A large scale comparison might be peak-load energy production by a dam. When electricity demands are not high, water is pumped up hill to a reservoir and stored. When the demand for electricity exceeds production by the dam alone, the water is released to run turbines and produce extra electricity. Remember that useful energy in molecular terms is contained in bonds. Therefore, the cell takes advantage of a pump by capturing energy in the bonds of adenine tri-phosphate (ATP).

Elements of the membrane, both protein and lipid, are continuously replaced. Since the very atoms that comprise their structure are no different after use, they can truly be re-used in the endless cycle of growth.

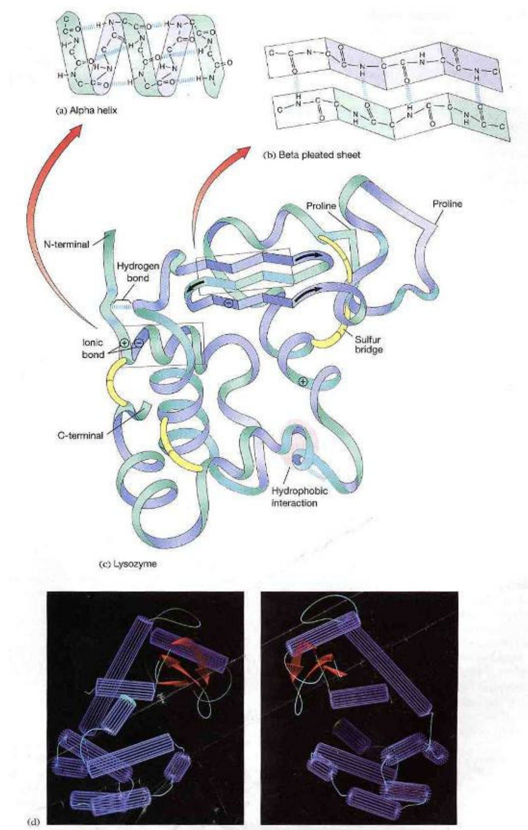


Image 38: Protein structures. Taken from *Biology*. Arms & Camp, 1995.

The complexity of protein structures should also be considered as a means of understanding biochemical applications in architecture. The protein is a combination of twenty amino acids arranged in series to produce inter-molecular interactions that allow it to fold on four different levels. The primary structure involves the actual sequence of amino acids. Secondary structure results in interactions between these amino acids, like hydrogen bonding. Typically, these are manifested as an alpha helix or beta sheets. The helixes and sheets then interact to create the tertiary structure. This is determined by ionic and hydrophobic interactions, and defines the over all shape that the protein will take. Finally, many complexes are actually several proteins interacting together, and these interactions create the quaternary structure.

All of these complex molecules interact to form cells, the basic 'building block' of life. There are two types of cells, prokaryotic and eukaryotic, and they differ in levels of organizational complexity (Image 39). Plants and animals are comprised of eukaryotes, the more complex form, and these are subdivided into functional groups known as 'organelles.' The nucleus is a commonly known organelle, and it contains the DNA of the cell. There are also mitochondria that process energy, chloroplasts (in plants) that utilize light from the sun to store energy, and a variety of other organelles that work to form proteins, control waste, and provide structure to the cell. Each of these organelles is surrounded by its own plasma membrane which serve to interact with the interstitial space of the cell in different ways depending on the function of the organelle.

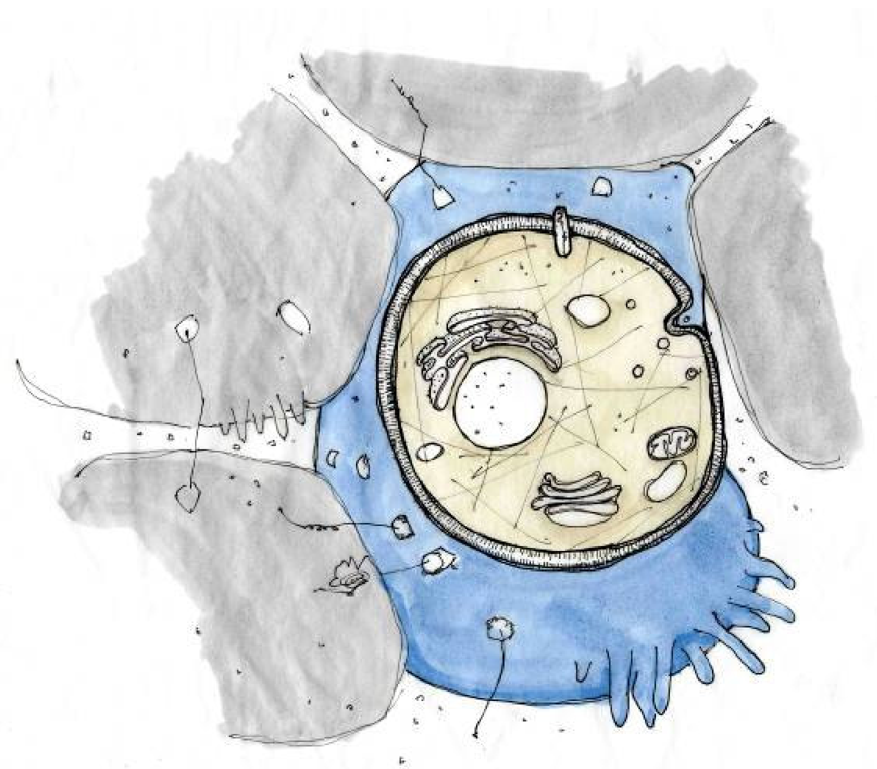


Image 39: Section of eukaryotic cell.

. . Appendix B:

Precedents – Sustainability

Consider the cherry tree: thousands of blossoms create fruit for birds, humans, and other animals, in order that one pit might eventually fall to the ground, take root, and grow. Who would look at the ground littered with cherry blossoms and complain, "How inefficient and wasteful!" The tree makes copious blossoms and fruit without depleting its environment. Once they fall to the ground, their materials decompose and break down into nutrients that nourish microorganisms, insects, plants, animals, and soil. Although the tree actually makes more 'product' than it needs for its own success in an ecosystem, this abundance has evolved (through millions of years of success and failure or, in business terms, R&D), to serve rich and varied purposes. In fact, the tree's fecundity nourishes just about everything around it.

What might the human built world look like if a cherry tree had produced it?

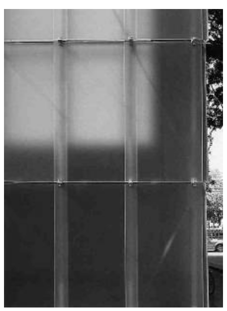
--William McDonough and Michael Braungart

Image 40: Two trees grow on a precarious hillside in Cyprus.

Skins

It isn't easy to draw the line between a useful skin and ornamental packaging. Even in the heyday of modernism, the demands for honesty and truthfulness in the material were difficult to fulfill. As technical requirements grow ever more complex and challenging and insulation guidelines increasingly rigid, nearly every external skin becomes a multi-layered system whose surfaces rarely give us any insight into the interior life of the building.

--Christian Schittich



In terms of comfort, functional properties take precedence over structural, aesthetic, and ecological aspects. However, all four categories must be given equal weight in a "total building system," since they are interdependent and bear a direct influence on each other. Thus the physiological properties of an external wall are dependent on its structure, sequences of layers and material properties. The ecological characteristics in turn, are determined by functional i.e. physiological aspects such as insulating and shading properties. Questions of construction, too, such as the selection of materials determine the energy consumption in construction by virtue of their corresponding primary energy content. All four aspects must be fully considered to create architecture that is – in a Semperian sense – guided by reason… while asserting its membership in the liberal arts through quality in design.

-- Werner Lang

Image 41 (Left): Peter Zumthor – Kunsthaus Bregenz.

Image 42 (Top Right): Herzog & de Meuron – Wiesbaden Administration Building.

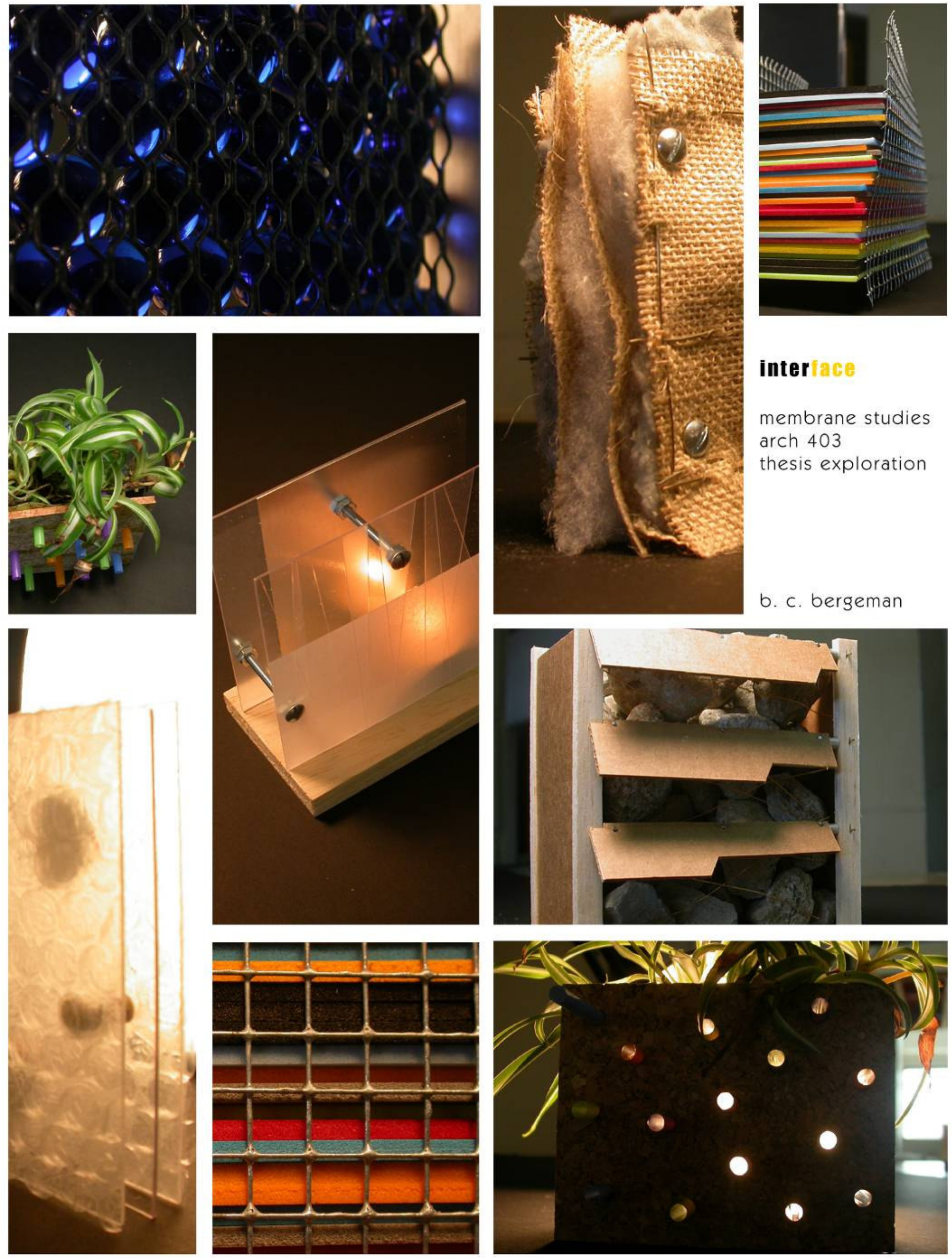
Image 43 (Bottom Right): Herzog de Meuron – Dominus Winery.

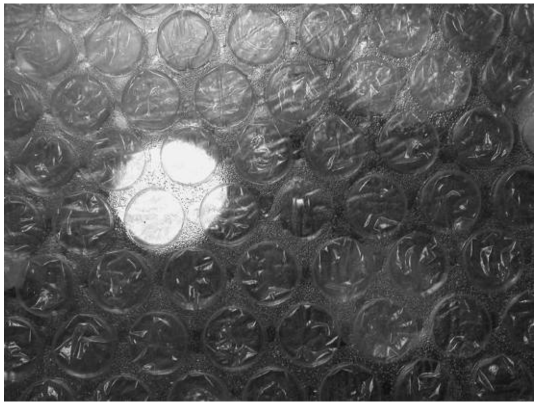
Images taken from *In Detail: Building Skins*. Schittish, ed., 2001.

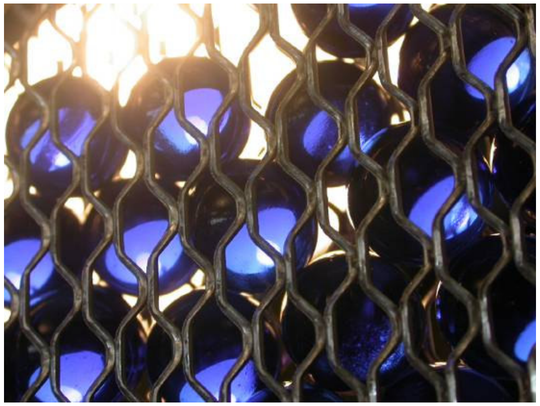
. . Appendix C:

Early Experiments - Interface

An early experiment into my thesis was to test new modes of 'membrane' in the built world. To juxtapose mass with light, earth, cork, and plants were held together with plastic straws. While it appears solid from some angles, it can be quite luminous from another. To play with light, Plexiglas, small mirrors at multiple angles, and bubble wrap created sharp and soft reflections. In another 'light' experiment, the interstitial space between reflective metal and 'frosted' Plexiglas was filled with the warmth and light of a small candle. A wood and metal box filled with small rocks experimented with mass, while lint and burlap tested a flexible, breathable membrane. Still another utilized layers of colored foam and wire mesh, and the final played with the geometry and quality of light filtering through blue marbles.







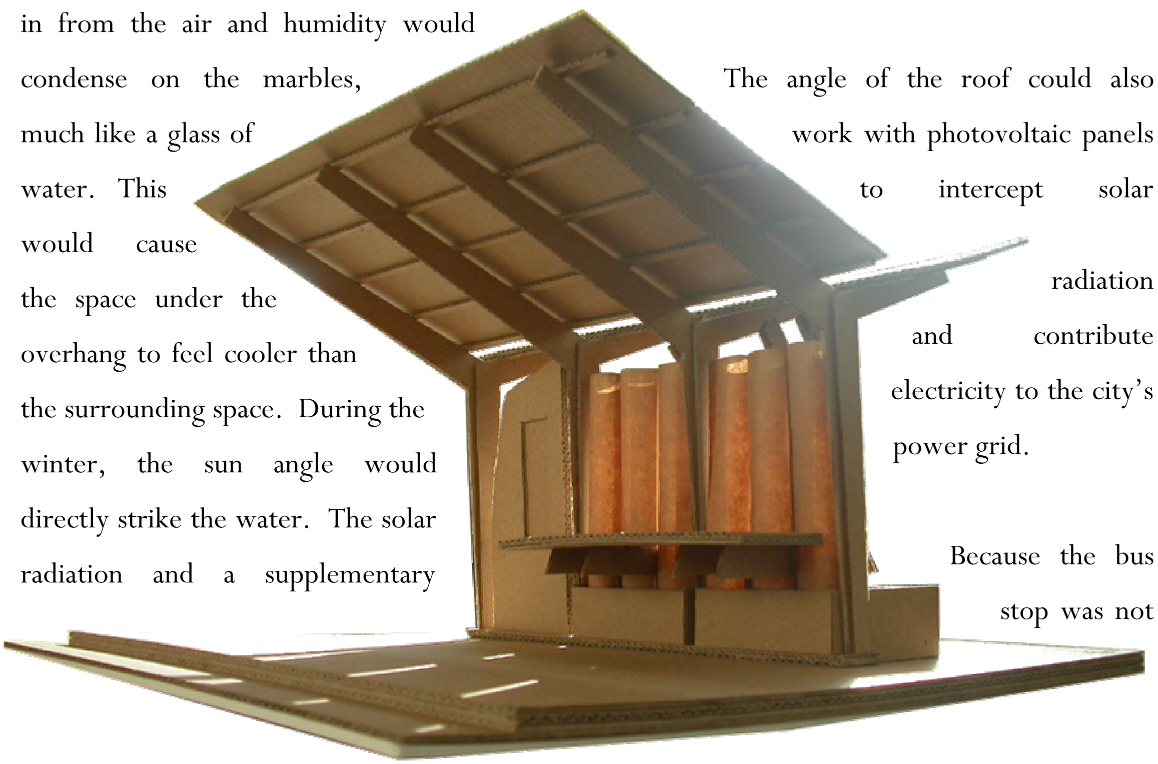
While my expressions of these concepts were small, their execution could be quite large in scale. What if marbles were used within walls in tropical climates to collect humidity, or rock walls, shaded from direct sun, filtered air and water while serving as a high mass element to a design? Can our buildings be as dynamic and integrated with the cycles of night and day and the seasons of the year as plants and other forms of life are? What other lessons can we learn from cellular systems?

Bus Stop

One of the goals for this project was to create a reproducible image for the city of Muncie Public Transit System. Thus, an easily identifiable roof line became the defining element of these small structures.

Water collected on the roof would flow to centrally located water tubes, which would be surrounded by glass marbles. During the summer, the shaded water would absorb heat in from the air and humidity would condense on the marbles, much like a glass of water. This would cause the space under the overhang to feel cooler than the surrounding space. During the winter, the sun angle would directly strike the water. The solar radiation and a supplementary system would keep the water warm, which in turn would radiate out to the people waiting for the bus.

At night, the tubes would serve as signage; different colors of light would signify different bus lines. The water would also be used to water the street trees of that block, integrating it with the greater context and enhancing the beauty of the overall community.



The angle of the roof could also work with photovoltaic panels to intercept solar radiation and contribute electricity to the city's power grid.

Because the bus stop was not enclosed, it was difficult to define the interior and exterior elements of the membrane. Without further study and a full scale model, it would be impossible to determine the success of the system in a real-world application.

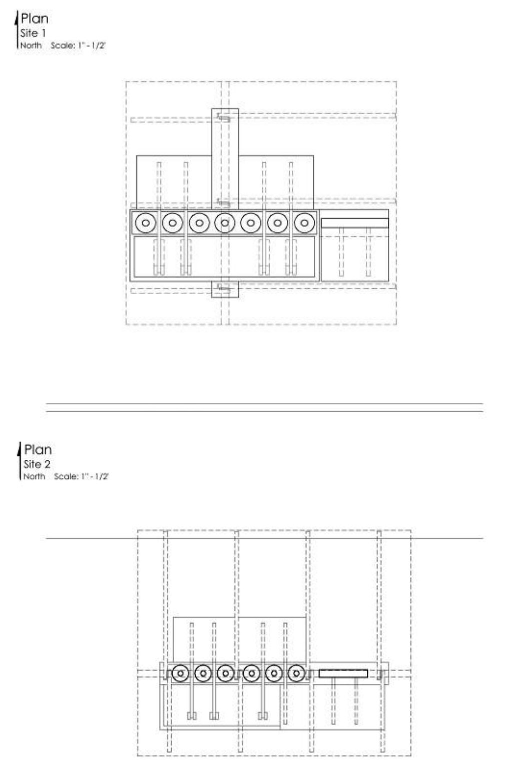
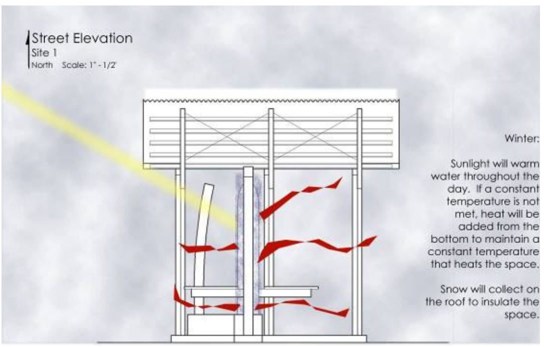
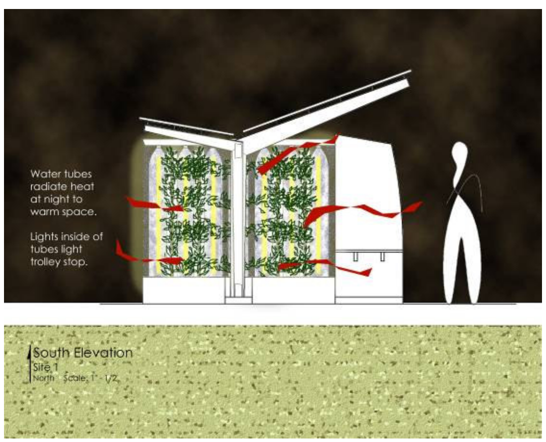


Figure 18: Floor Plan can be reconfigured depending on orientation to the sun.

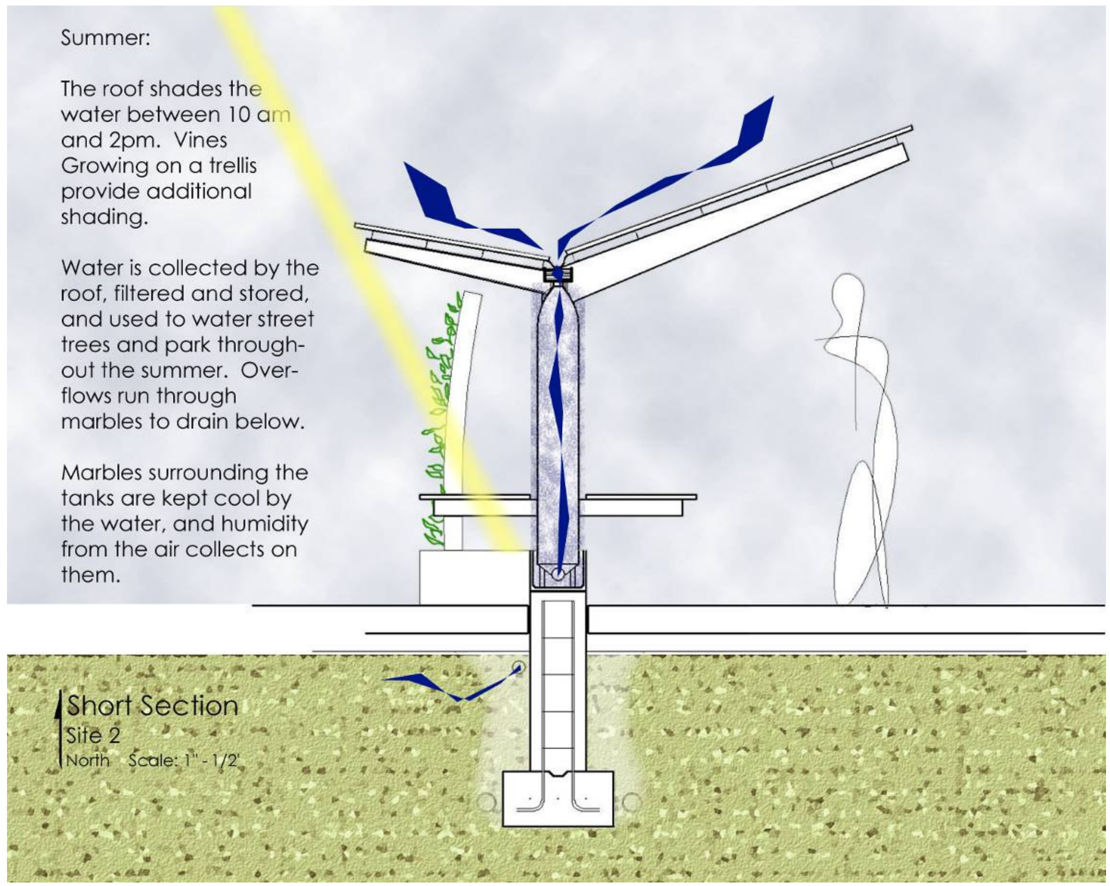
Existing bus stop.



Winter, day.

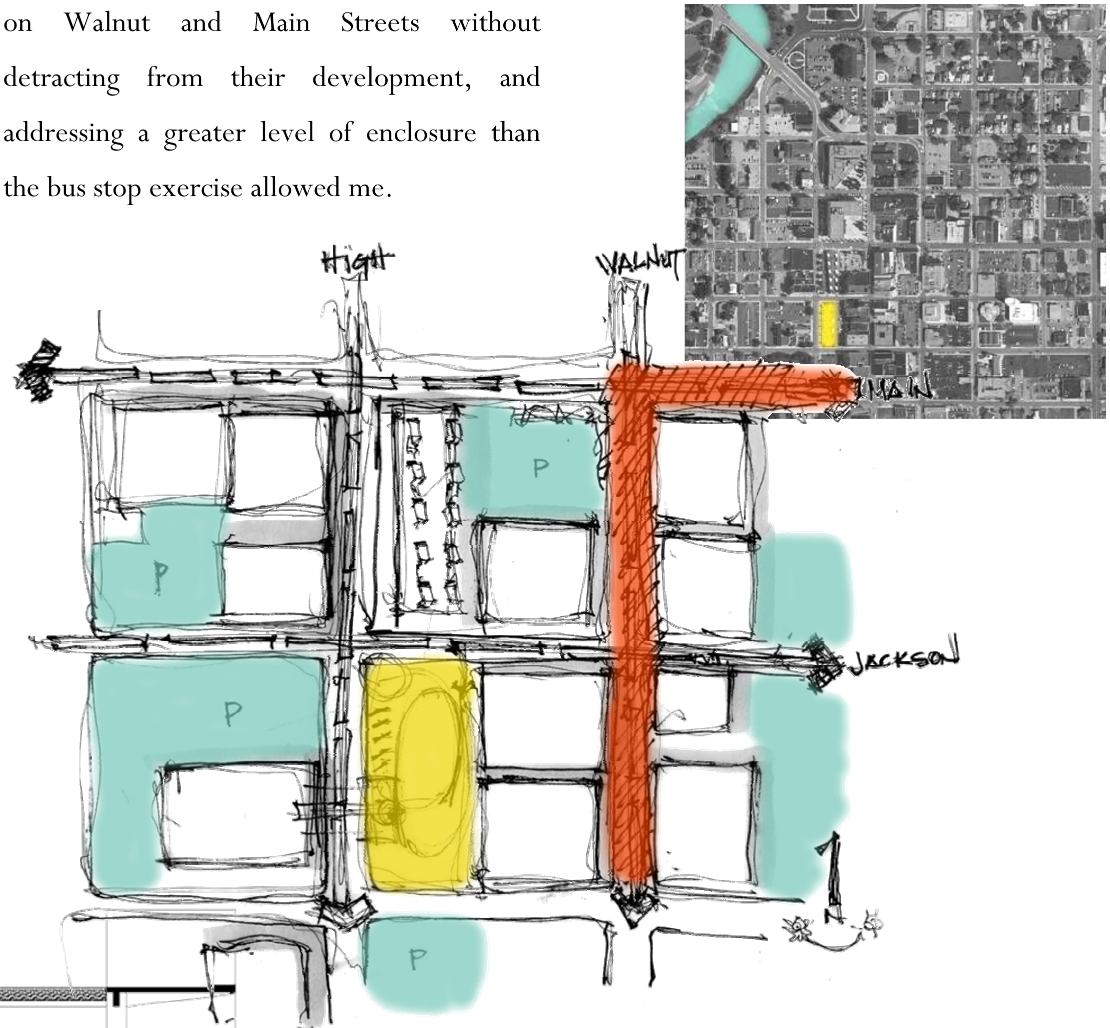


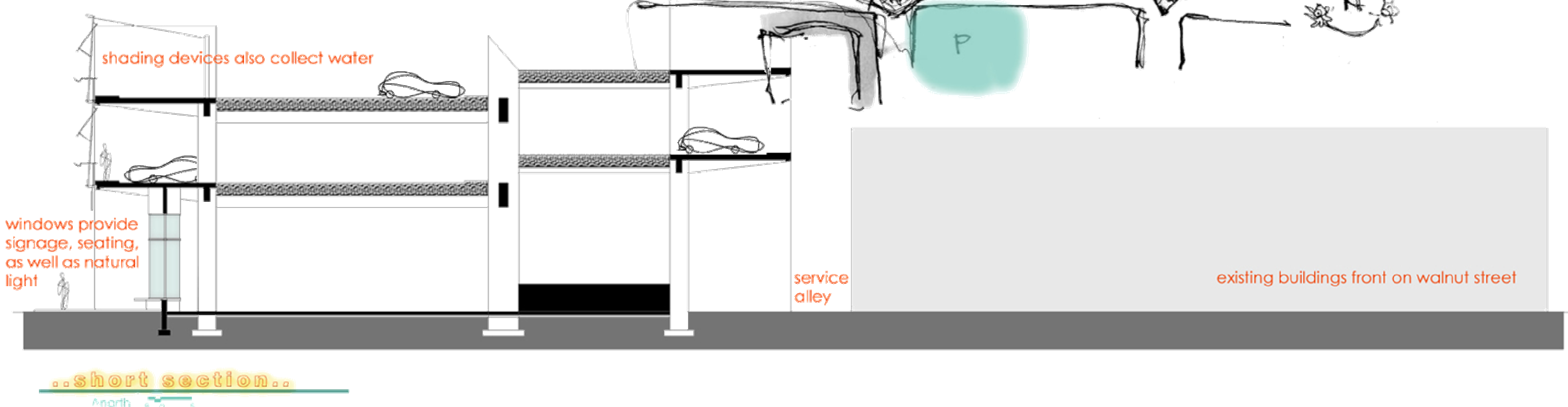
Summer, night.



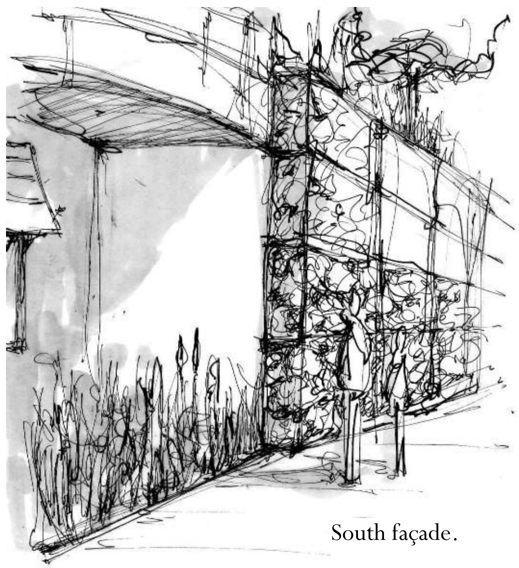
Parking Garage

The goal was to design a parking garage that would be as good for the community as the environment, while testing the cell/architecture model in a larger scale project. This also included integrating multiple functions into one building, mitigating urban run-off, supporting growth on Walnut and Main Streets without detracting from their development, and addressing a greater level of enclosure than the bus stop exercise allowed me.



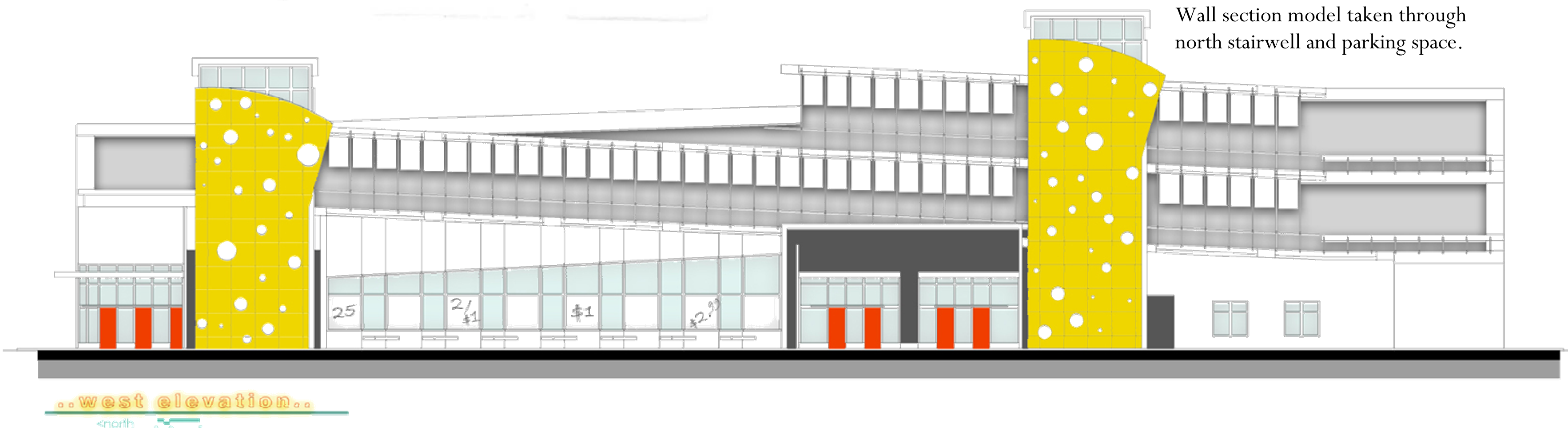


The solution involved a street-level urban grocery store with a deli for the many people who lived and worked nearby. The parking surface above consisted of a crushed stone base, allowing the inherent ramp structure to channel water and urban runoff to living cores that would address pollutants before being released into the waste stream. The shading and thermal mass of the building would keep cars cool during the summer, reducing the need for air-conditioning. The angled glass of the west façade would allow light deep into the building, provide signage on High Street, and create seating opportunities and human-scaled streetscape.



South façade.

Wall section model taken through north stairwell and parking space.



Solar Gain

The project goal was to capture the energy from the sun to heat a room through the use of a sun space.

First, I constructed 4 models to represent potential building façades. I cut 12” x 12” x ¼” tile and layered them 3 deep to achieve the wall thickness. I used rigid foam insulation with an R-value of 5 on the other five surfaces to insulate against heat transfer. Then, I exposed the models to sunlight for a 12 hour period on 4 December 2004 while taking temperature readings every 2 hours. On 6 December 2004 I exposed each box to 2 hours of direct radiation from a 100W light bulb in an unheated garage, taking

measurements every ten minutes. This was to achieve more detailed readings on the function of each model.

[4 December 2004] Mostly sunny day, with some hazy clouds around noon that may have limited solar radiation. Wind speeds averaged between 7 and 16 mph from the WSW, which could have affected the exposed models due to convection. Temperatures ranged between 32 and 52^{o}F. On December 21 at 40^{o} north latitude, a vertical surface will receive approximately 1646 Btu/h ft^2.[2]

[6 December 2004] Cloudy with rain early in the day, but models were only exposed to light bulb within garage. Interior temperature of 51^{o}F.

The models all showed change when exposed to a heating source. The solar experiment indicates a delay of approximately 2 hours, meaning a solar-heated building will have a time lapse that must be addressed in the selection and thickness of materials.

The control performed well under both the light bulb and sun, indicating that the key to a successful sunspace is a lot of mass.

[2] Reynolds, John and Benjamin Stein. *Mechanical and Electrical Equipment for Buildings*. 9th Edition. New York: John Wiley & Sons, 2000.

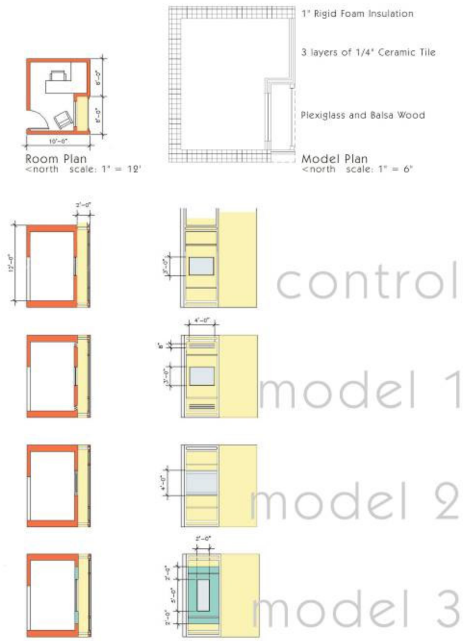
Model 1, which was vented at the top and bottom, was the coldest initially in both experiments, but reached the highest temperature when exposed the sun across the day. It was also the most responsive when exposed to the light bulb. The vents might allow a quicker transfer of heat between the sunspace and the room, but at the same time, they allow a greater heat loss.

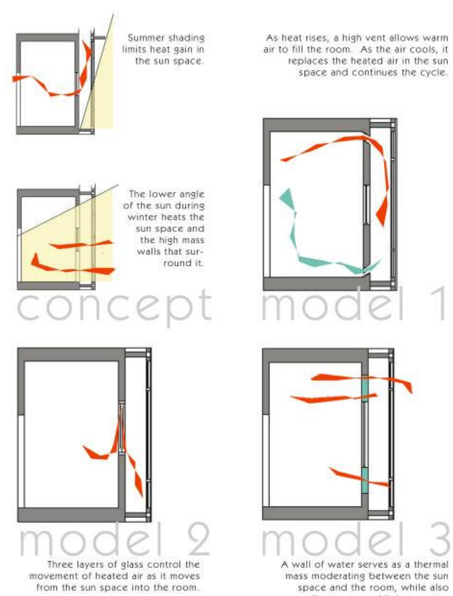
Model 2, which utilized 3 unsealed panes of glass, did not perform particularly well when exposed to the light bulb, but did see a greater temperature increase than the water model when exposed to the sun. Perhaps it takes more time to realize the benefit of this design.

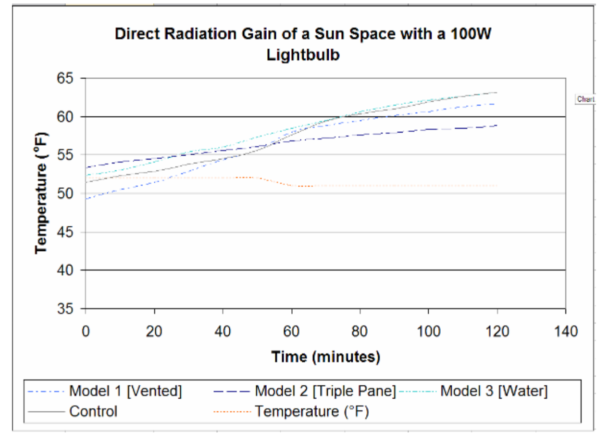
Model 3, which contained water as a thermal mass, did not transfer as much heat as the ceramic tile. It also leaked a lot, although I spent a considerable amount of time trying different methods of sealing it. I thought it would hold heat longer than the other models, but it actually lost heat the quickest. This may have been due to poor construction and design. I realized later the water should have been contained in a dark, heavy material to optimize heat transfer, but I wanted to to allow maximum daylight to enter the room.

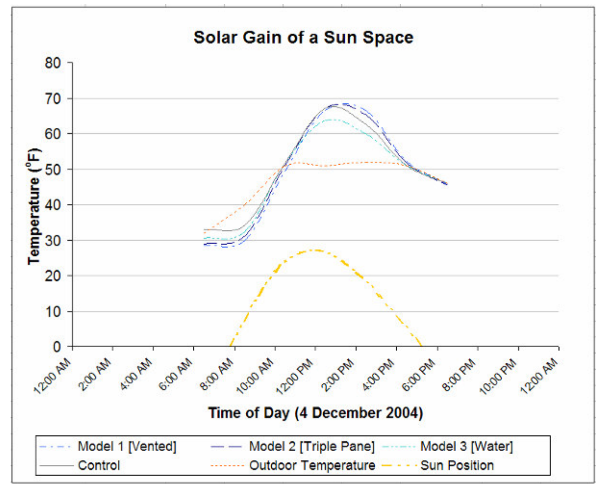
The models were not as well sealed as they could have been, and leaving them outside during freeze/thaw and changes in humidity was tough on them. Additionally, the materials used do not necessarily correlate with full scale buildings. A future test might be to continuously expose them for several days to see total temperature change and account for error due to environmental influences. In reality, the rooms would also be next to other rooms undergoing similar changes. I would like to build a model with several different spaces in it to further test the transfer of heat in a building.

The use of a sunspace and thermal mass raised the temperature of air about 15°F and 12°F in two different experiments, equating to about 70 and 51 Btu respectively. As an interesting comparison, my roommates and I used 36.54 therms heating air and water this past month, according to our gas bill. This is equivalent to 3,653,127.6 Btu, or about 135,301 Btu/day. For an 850 sq ft house, the additional heating of 70 Btu/ft^3 could have a significant impact during the winter.





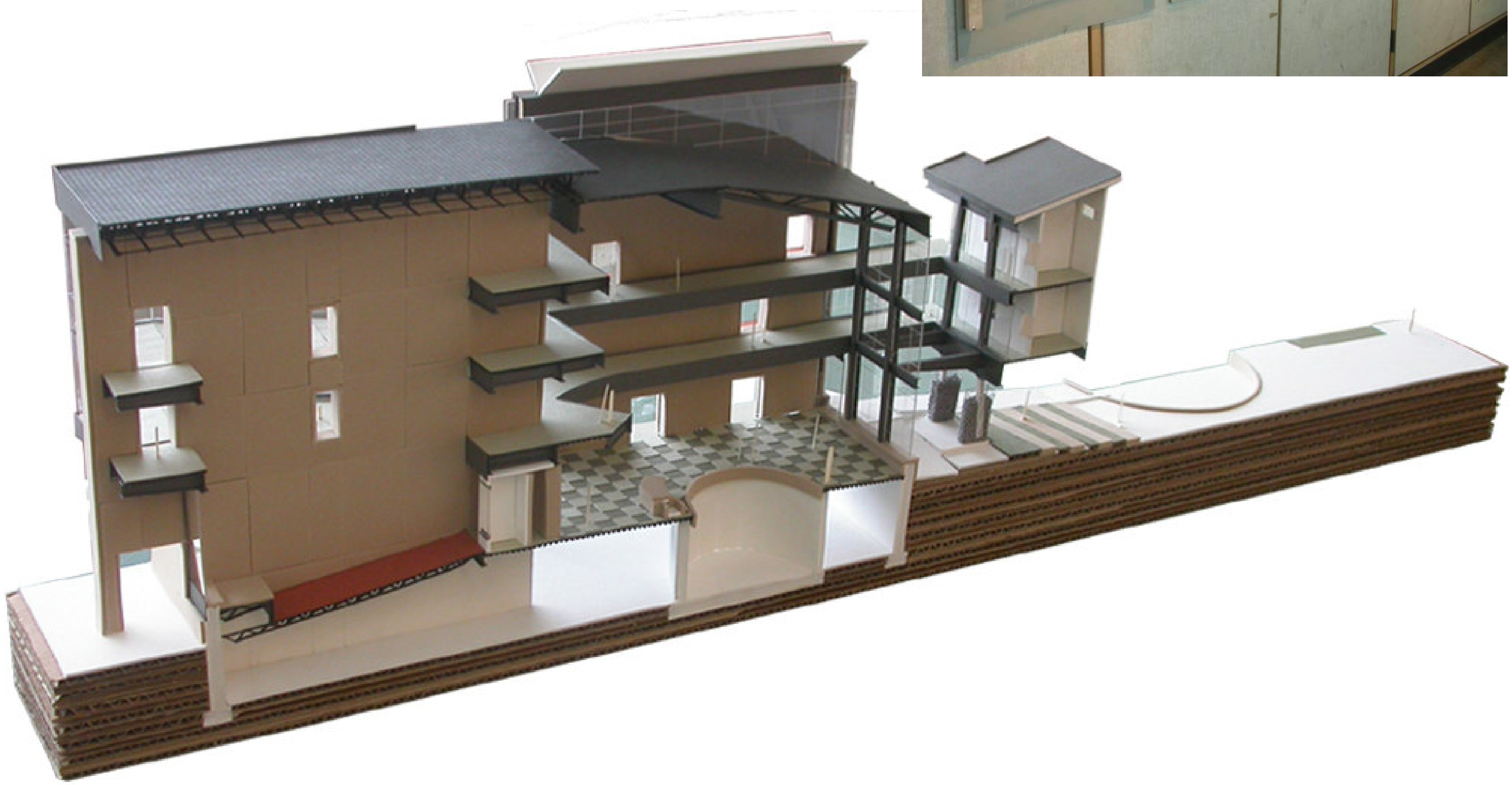




. . Appendix D:

Thesis Presentation

Four Boards, Section Model, and PowerPoint Presentation, along with several study models and images.



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All imagery is the work of Brianne Bergeman unless otherwise noted.